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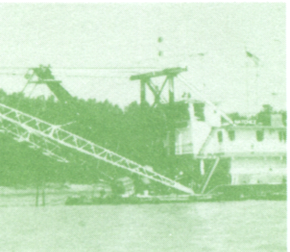

DREDGING OPERATIONS TECHNICAL
SUPPORT PROGRAM

TECHNICAL REPORT D-91-1

A FRAMEWORK FOR ASSESSING THE NEED FOR SEASONAL RESTRICTIONS ON DREDGING AND DISPOSAL OPERATIONS

by

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13. ABSTRACT *(Maximum 200 words)*
Seasonal restrictions on dredging and/or disposal operations are based upon concerns about potential dredging- or disposal-induced negative impacts to biological resources. In many cases, however, information on the degree to which either naturally occurring or dredging-induced environmental alterations directly or indirectly affect organisms is poorly quantified, in which case restrictions are based upon a "reason to believe" notion.

This report addresses the general acceptability of seasonal restrictions through a compilation of available information on physical-chemical environmental alterations associated with dredging and disposal operations, and critical information regarding the effects of these alterations on principal biological resources. Based on this information, a method for evaluating existing or proposed seasonal restrictions on dredging and/or disposal operations is presented. This framework reflects the present understanding of effects of dredging- or disposal-induced, as well as naturally occurring, environmental alterations upon biological resources. In many cases, the magnitude of dredging- or disposal-induced alterations falls well within the range of naturally occurring phenomena and imposes little or no additional stress upon resource populations. In some cases, however, the magnitude of alterations may exceed that which occurs naturally, whereby

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concerns about dredging- or disposal-induced alterations are justified and should be considered when planning a project.

This framework provides a means for Corps personnel to quantify seasonal restriction considerations relative to a project during its environmental assessment phase and to develop an understanding of any potential problem areas that may need to be considered. The framework may be used to challenge restrictions that are found to be unsupported by available technical information.

In addition to placing dredging- or disposal-induced alterations in perspective, this report presents suggested approaches to encourage interagency coordination and cooperation in dealing with unresolved issues. All of the examples discussed are based upon two criteria: (a) all those involved must recognize the importance of natural environmental unpredictability and variability, particularly in estuarine and marine systems, as related to the tolerances of protected biological resources, and (b) cooperation among resource agencies, not antagonism, is of paramount importance.

PREFACE

The study described herein was sponsored by the Dredging Operations Technical Support (DOTS) Program of the Headquarters, US Army Corps of Engineers (HQUSACE). The DOTS Program is managed by the Environmental Effects of Dredging Programs (EEDP) of the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES).

The report was prepared by Dr. Mark W. LaSalle with technical contributions provided by Dr. Douglas G. Clarke, EL, WES; Dr. Jurij Homziak, Mississippi Cooperative Extension Service/Sea Grant; Mr. John D. Lunz, Science Applications International Corporation; and Dr. Thomas J. Fredette, US Army Engineer (USAE) Division, New England.

The study was conducted under the general supervision of Mr. Edward J. Pullen, Chief, Coastal Ecology Group, Environmental Resources Division (ERD), EL. Technical critiques were provided by Messrs. David A. Nelson, ERD; James Reese, USAE Division, North Pacific; Rob Hauch, USAE District, Galveston; Mario Paula, USAE District, New York; Phil Payonk, USAE District, Wilmington; Paul Bradley, USAE District, Mobile; Don Borkowski, USAE District, Buffalo; and David Mathis, HQUSACE.

Dr. Robert M. Engler was Program Manager, EEDP; Mr. Thomas R. Patin was Program Manager, DOTS. Technical monitor for the work was Mr. Joseph Wilson, HQUSACE. Dr. Conrad J. Kirby was Chief, ERD, and Dr. John Harrison was Chief, EL.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

A FRAMEWORK FOR ASSESSING THE NEED FOR SEASONAL RESTRICTIONS ON DREDGING AND DISPOSAL OPERATIONS

PART I: INTRODUCTION

Background

1. Seasonal restrictions on dredging/disposal operations are often imposed by resources management agencies in an effort to avoid or minimize the potentially detrimental effects of these operations on biological resources. Imposition of these restrictions is based largely upon suppositions about the effects of dredging/disposal-induced environmental alterations on a resource. In many cases, however, information on the degree to which either naturally occurring or dredging/disposal-induced alterations directly or indirectly affect organisms is poorly quantified, in which case restrictions are based upon a "reason to believe" notion. In these cases, when an effect cannot be refuted or supported, a resource agency can feel justified in "playing it safe." In some cases, however, restrictions may be maintained in the face of technical information refuting the restriction. This can lead to confusion and confrontation between Corps Districts, charged with maintaining navigable waterways, and State and Federal resource agencies, charged with protecting biological resources. As an added problem, restrictions concerning a specific resource may vary from state to state or from time to time, and in many cases, for different and completely unrelated reasons.

2. All Corps Districts have a mandate to conduct work in an environmentally acceptable manner. Toward this goal, Districts desire a good working relationship with State and Federal resource management agencies having similar desires toward protecting biological resources. Corps Districts attempt to comply with seasonally restrictive requests on dredging and disposal operations, particularly when these restrictions are based on sound technical information and when it is practical to do so. In some instances, however, restrictions that are not technically defensible may complicate scheduling, funding, and contracting, increase project costs, and increase the hazards of field operations. In these cases, restrictions should be reevaluated, based upon available technical information about the effects of specific alterations on the biological resource(s) in question.

3. This report is an attempt to technically clarify the subject of seasonal restrictions on dredging/disposal operations through the following objectives:

a. Document the types, occurrence, and the apparent technical reasons for seasonal restrictions on dredging and disposal activities.

b. Identify specific criteria, based on available information, that would encourage more objective determinations of the need for seasonal restrictions on dredging/disposal operations.

c. Suggest a method, employing the available technical information about dredging and disposal effects, to achieve more efficient, consistent, and objective reviews of proposed dredging and disposal projects on a case-by-case basis.

d. Review the commonly used types of dredging and disposal operations and the associated environmental alterations produced by these operations.

e. Review the available technical information on the effects of dredging- and disposal-induced environmental alterations on aquatic organisms.

4. The basis for the present report was a review of seasonal restrictions on bucket dredging operations reported by Lunz, Clarke, and Fredette (1984) and similar reviews by Profiles Research

and Consulting Groups, Inc. (1980), Kantor (1984), and Lunz (1987). The present report expands the subject to include other dredge types and disposal operations.

Types and Occurrence of Seasonal Restrictions on Dredging and Disposal Operations

5. The subject of environmental windows (seasonal restrictions) associated with dredging operations was initially addressed on a Corps-wide basis through a working group of Corps and dredging industry representatives convened in 1985 to address a number of topics relative to the scheduling of contract dredging work. Information on seasonal restrictions collected during this survey indicated that a large proportion (65 of 240 projects, 27 percent) of projects scheduled during the 1985 fiscal year were affected by one or more restrictions, in some cases as many as three per project. To obtain additional information on the topic, a telephone and mail survey of coastal and Great Lakes Corps Division and District offices was conducted between 1985 and 1989 to obtain information on the types of, and technical rationale for, seasonal restrictions requested or imposed on dredging and disposal operations. Respondents were asked for specific information on (a) the subject of a given restriction, that is, the type(s) of resource being protected; (b) the potential detrimental effect or effects forming the underlying reason for a restriction, if specified; (c) the project type, specific project activity (or activities), and environmental alteration(s) of concern; (d) the dates of a restriction; and (e) the agency or agencies requesting a restriction.

6. For those Divisions and Districts that responded to the survey, a summary of the types of resources being protected and the reasons given for restrictions to protect them are presented in Table 1 (see page 6). The resources of concern range from single species or a group of species to broad categories (e.g., habitat type, community type). Protected resources include such divergent types as anadromous fishes, bird colonies, shellfishes, seagrass beds, turtles, marine mammals, etc. Of these, anadromous fishes and bird colonies were the most frequently referenced (about 50 percent of total responses). Both State and Federal agencies are often involved in requesting these restrictions.

7. There is minimal consistency in the requirement for and application of seasonal restrictions among Districts having similar biological resources. For example, within the different Districts included in this survey, penaeid shrimp would certainly be classified as significant biological resources of the Wilmington (North Carolina), Charleston (South Carolina), Jacksonville (Florida), Mobile (Alabama, Mississippi, Florida), New Orleans (Louisiana), and Galveston (Texas) Districts. Among these Districts, the shrimp fisheries of Texas, Louisiana, Mississippi, Alabama, and Florida are larger than those of the Carolinas, and yet seasonal restrictions to protect penaeid shrimp appear to occur only in the Wilmington and Galveston Districts. Along the northeast Atlantic and northwest Pacific coast, as well as the Great Lakes, seasonal restrictions to protect upstream migrating adult anadromous fishes exist, but for a number of apparently different and somewhat unrelated reasons.

8. Concerns cited in this survey and by previous reviews of potential dredging and disposal impacts (Windom 1976, Morton 1977, Allen and Hardy 1980) include:

a. Physical effects of elevated suspended sediment concentrations on the health and survival of fishes.

b. Effect of the sediment plume on the behavior of migrating fishes.

c. Entrainment by cutterhead and hopper dredges.

d. Impacts from dissolved oxygen reduction.

e. Physical disturbance of spawning and feeding grounds.

9. The reasons given for justifying restrictions range from technically valid arguments about the potential effects of a dredge-induced alteration on the resource, to broad "gut feeling" responses, to no stated reason at all. In many cases, the technical information needed to either support or refute the contention of a detrimental effect is not available (see Part V), in which case a resource agency may feel justified in "playing it safe."

Table 1
Summary of Seasonal Restrictions on Dredging and Disposal Operations in Coastal and Great Lakes Areas

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
New England	Smelt (*Osmerus mordax*) American shad (*Alosa sapidissima*)	Avoid disruption of spawning via dredge-related water quality impacts	April-September (variable by state)
	Alewife (*Alosa pseudoharengus*) Blueback herring (*Alosa aestivalis*) Coho salmon (*Oncorhynchus kisutch*)	Avoid disruption of migration via dredge-related water quality impacts	October-March
	Shortnose sturgeon (*Acipenser brevirostrum*)	Avoid dredge-related water quality disruptions to: migration spawning feeding by juveniles	 February-September July-August July-November
	Winter flounder (*Pseudopleuronectes americanus*)	Avoid disruption of spawning via dredge-related water quality impacts	February-April
	Shellfishes (shrimps and crabs)	Avoid disruption of spawning via dredge-related water quality impacts	May-September
	Eastern oyster (*Crassostrea virginica*)	Avoid disruption of spawning via dredge-related water quality impacts	1 June-30 September (variable based on induction of spawning)
	Hard clam (*Mercenaria mercenaria*)	Avoid disruption of spawning via dredge-related water quality impacts	June-September
	Lobster (*Homerus americanus*)	Avoid disruption of inshore migration via dredge-related water quality impacts	June-September
North Atlantic/ New York	Finfishes and shellfishes	Avoid disturbance to spawning in surf zone	15 May-30 June

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
North Atlantic/ New York (Continued)	Fisheries resources	Minimize stress on overwintering resources	January-February
		Minimize stress on resources during periods of peak water temperature when dissolved oxygen is low	July-August
	Commercial and recreational fishes	Avoid adult and larval mortality due to elevated turbidity	1 June-30 September
	General marine life (fishes and shellfishes) and aquatic recreation	Minimize disturbance during spawning season and avoid interference with aquatic recreation	15 June-30 September
	Waterfowl and wildlife	Avoid noise disturbance	15 May-30 June
	Piping plover (*Charadrius melodus*) Roseate tern (*Sterna dougalli*)	Avoid disturbance of inhabited areas	15 March-1 September
	Walleye (*Stizostedion vitreum vitreum*)	Avoid disturbance of spawning area	1 July-August
	Winter flounder (*Pseudopleuronectes americanus*)	Avoid disturbance during spawning	15 September-June
	American eel (*Anguilla rostrata*) Atlantic sturgeon (*Scipenser oxyrhynchus*) Striped bass (*Morone saxatilis*) Blueback herring (*Alosa aestivalis*) Alewife (*Alosa pseudoharengus*) American shad (*Alosa sapidissima*) Bay anchovy (*Anchoa mitchilli*) Atlantic croaker (*Micropogonias undulatus*) Weakfish (*Cynoscion regalis*) Gray snapper (*Lutjanus griseus*)	Avoid potential disturbance by turbidity and reduced dissolved oxygen during spring and fall migrations	15 April-30 September (variable)

(Continued)

Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
North Atlantic/ New York (Continued)	Crevalle jack (*Caranx hippos*) Sea robin (*Prionotus* spp.) Hard clam (*Mercenaria mercenaria*) Bay scallop (*Argopecten irradicans*)	Avoid disturbance of spawning activity by suspension of organic material	1 June-30 September
	Surf clam (*Spisula solidissima*) Blue mussel (*Mytilus edulus*)	Avoid high levels of turbidity and potential reduction in gas exchange across gill surfaces, abrasion of body epithelium, packing of the gut with ingested solids, disruption of gill tissues, reduction of stored metabolic reserves	15 May-30 June
Baltimore	Submersed aquatic plants	Avoid burial of plants by sediment	May-September
	White perch (*Morone americana*) Striped bass (*Morone saxatilis*)	Avoid physical disturbance of fish spawning areas and/or blockage of access routes to spawning areas	15 March-15 June
	Yellow perch (*Perca flavescens*)		15 February-15 June
	Eastern oyster (*Crassostrea virginica*) (Adults)	Protection from sedimentation during periods of cold water temperatures when oysters have a reduced ability to cleanse themselves of suspended sediment	15 December-28 February (if project is within 500 yd (450 m) of an oyster bar)
	(Larvae)	Entrainment by hydraulic dredging operations	1 June-30 September (if project is within 500 yd (450 m) of an oyster bar)

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
North Atlantic/ Baltimore (Continued)	Eggs and larvae of: Bay anchovy (*Anchoa mitchilli*) Naked goby (*Gobiosoma bosci*)	Entrainment by hydraulic dredging operations	April-August
North Atlantic/ Norfolk	Easter oyster (*Crassostrea virginica*) (Adults)	Protection of oyster beds from sedimentation and gill clogging during periods of low pumping rates	January-February (variable)
	(Larvae)	Protection of oyster beds from sedimentation during setting of spat	July-September (variable)
	Shellfish beds (near marinas, seasonal health condemnation)	Reduce effects of chemical releases (from fuels, paint, and overboard disposal of wastes), dissolved oxygen reduction, and boat-induced turbidity	Variable
	Striped bass (*Morone saxatilis*) American shad (*Alosa sapidissima*)	Reduce impacts on spawning and nursery habitats from turbidity, dissolved oxygen reduction, clogging of gills, and physical disturbance of habitat	15 March-30 June
	Alewife (*Alosa pseudoharengus*) Blueback herring (*Alosa aestivalis*)	Avoid turbidity-induced channel blockage affecting migration	May-August (variable)
	General fisheries	Minimize potential for resuspension of dioxin-contaminated sediment and likelihood of biological uptake by fishes in the Potomac River during the most active time of the year	15 March-1 November
	Shorebirds	Avoid disturbance (noise) of nesting activities in rookeries located on emergent dredged material islands	April-September (variable)

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
North Atlantic/ Norfolk (Continued)	Bald eagle (*Haliaeetus leucocephalus*)	Avoid noise impairment of nesting and rearing of young	December-June
	Submersed aquatic vegetation	Avoid impacts from turbidity, sedimentation, burial, and physical removal of plants during most active growth and reproductive season	1 March-30 June
	Biological oxygen demand	Avoid water quality degradation in areas of slow or no flushing and in areas containing highly organic muds	mid May-September
South Atlantic/ Wilmington	Penaeid shrimp and finfish	No reasons given	April-September
	American shad (*Alosa sapidissima*) Blueback herring (*Alosa aestivalis*)	No reasons given	March-August
	Juvenile pompano (*Trachinotus carolinus*) Northern kingfish (*Menticirrhus saxatilis*)	Avoid physical disturbance of the nursery area; smothering of benthic invertebrates serving as food	June-September
	Colonial-nesting waterbirds	Avoid physical disturbance of nesting activities during disposal operations	April-July
	Piping plover (*Charadrius melodus*)	Avoid disturbance of nesting activity during beach disposal operations near nesting areas	1 April-31 July
	Sea turtles	Avoid physical disturbance of nesting habitat during beach renourishment or beach disposal	March-November (disposal is allowed if monitoring and nest relocation are practiced)

(Continued)

Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
South Atlantic/ Charleston) (Continued)	Short-nose sturgeon (*Acipenser brevirostrum*)	Avoid turbidity-related impacts and possible interruption of migration	15 February-30 June (if possible)
	Fisheries resources (finfish and shrimp) (Larvae)	Avoid turbidity and related water quality-mediated impacts to younger organisms	1 March-1 December
	(Adults)	Avoid interruption of migration of larger organisms, particularly associated with inlet projects	
	Eastern oyster (*Crassostrea virginica*)	Avoid sedimentation-mediated mortality of adults and possible loss of substrate suitable for spat settlement	15 May-1 September (if possible)
		Avoid microbacteriological contamination of harvestable oysters from release of waters from dredged material containment areas	No absolute dates, but avoid 1 September-14 May, if possible
Savannah	Whales	Avoid collisions with dredge and service boats and/or injury from propellers	Open (observers)
	Marine turtles		July-December
	Manatees (*Trichechus manatus*)		June-September
	Least tern (*Sterna antillarum*)	Avoid disposal in sandy areas of disposal sites used for nesting	31 March-31 August
	Dissolved oxygen	Avoid dredging during period when dissolved oxygen is below 3.0 mg/L	June-October (variable)

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
South Atlantic/ Savannah (Continued)	Anadromous fishes (particularly striped bass (*Morone saxatilis*)	Avoid impacts from increased turbidity, resuspension of pollutants and decreased dissolved oxygen during spawning period: includes request to hold gates of Tide Gate/Sediment Basin Project open during this period	16 March-31 May
Jacksonville	Offshore live bottom reef communities	Avoid sedimentation or burial adjacent to borrow areas (borrow areas ≥ 150 m, deepwater and minimum amount of silt/clay)	No specific periods
	Manatees (*Trichechus manatus*)	Avoid injuries due to blasting, collisions, or harassment	Year-round
	Right whales (*Eubalaena glacialis*)	Avoid collision with ships or barges	November-April (except for emergency dredging when aerial surveys are required)
	Loggerhead turtle (*Caretta caretta*) Ridley turtle (*Lepidochelys kempi*) Green turtle (*Chelonia mydas*) Leatherback turtle (*Dermochelys coriacea*)	Avoid entrainment of young and nest destruction during dredging on beach	May-June
		Avoid beach nesting activities (nest relocations required)	March-November
		Avoid entrainment and damage to adults in channels during winter hibernation period and during spring mating period	1 December-31 August
	Seagrasses	Avoid sedimentation and associated interference with photosynthesis	April-November

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
South Atlantic/ Mobile (Florida portion of District only)	Shellfish harvesting	Avoid burial and pollution effects on shellfish beds	April-November
	Shore and wading bird breeding habitat Snowy plover (*Charadrius alexandrinus*) Least tern (*Sterna antillarum*) Plovers (*Charadrius* spp.)	Minimize the disruption of nesting and breeding habitat	April-June
	Bald eagle (*Haliaeetus leucocephalus*)	Avoid noise disturbance during nesting	November-February
	Striped bass (*Morone saxitilis*) Shortnose sturgeon (*Acipenser brevirostrum*)	Avoid dredge-related impacts on spawning activities	1 April-15 May
	Seagrasses	Avoid impacts from turbidity	31 March-1 December
Lower Mississippi River/New Orleans	Eastern oyster (*Crassostrea virginica*)	Avoid high levels of turbidity in vicinity of oyster beds during oyster harvesting periods	November-March
	Shorebirds	Avoid disruption of nesting site (physical) and activities (noise)	1 March-31 July (if project is within 500-1,000 ft (150-300 m) of rookery)
	Bald eagle (*Haliaeetus leucocephalus*)	Avoid disruption of nesting activities	15 October-30 April (if project is within 1.5 miles (2,500 m) of a nest site)
Southwestern/ Galveston	Birds (numerous coastal species)	Avoid disruption of nesting activities in rookeries on emergent dredged material disposal areas	1 March-31 August (if project is within 1,000 ft (300 m) of a rookery)

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
Southwestern/ Galveston (Continued)	Brown pelican (*Pelecanus occidentalis*)	Avoid disruption of nesting activities in rookeries on emergent dredged material disposal areas	1 February-31 July (if project is within 1,000 ft (300 m) of a rookery)
	Whooping crane (*Grus americana*)	Minimize human activity while cranes are present in overwintering area	15 October-15 April
	Commercial shrimp	Avoid disruption of migratory patterns of shrimp through the tidal passes connecting the Gulf of Mexico and the Laguna Madre estuary	1 May-31 July
South Pacific/ Los Angeles	Eelgrass (*Zostera marina*) beds and associated benthos	Avoid turbidity and associated reduction in photosynthetic capability	Year-round
		Avoid sedimentation and burial of beds and benthos	
	California grunion (*Leuresthes tenuis*)	Avoid disturbance of beach spawning habitat from beach or surf zone disposal via: (a) suspended sediment (toxic and behavioral impacts, water quality changes affecting spawning, burial or eggs), (b) physical disturbance of spawning habitat prior to spawning (e.g., alterations in penetrability, beach slope, sediment grain size, etc.), and (c) excavation of spawning sites via erosion from effluent	1 March-15 September

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
South Pacific/ Los Angeles (Continued)	California least tern (*Sterna antillarum browni*)	Avoid noise impairment of nesting activities	April-September
		Avoid effects of turbidity on shore and nearshore environments associated with prey (small surface fish), avoidance of the area, or obstruction of bird's prey spotting ability	
	Western snowy plover (*Charadrius alexandrinus nivosus*)	Avoid disturbance of nesting habitat and nesting activities	March-August
	Peregrin falcon (*Falco peregrinus anatum*)	Avoid noise impairment of nesting and and fledgling activities	February-June
	Southern sea otter (*Enhydra lutris nereis*)	Avoid disturbance of individuals or rafts of otters from operational noise and presence or proximity of people	Year-round except during summer months (mainly Morro Bay)
		Avoid turbidity impacts on kelp forest, clam beds, and sandy benthos within foraging habitat	
San Francisco	Pacific herring (*Clupea harengus pallasi*)	Avoid disturbance of spawning areas in shallow water	Case-by-case basis
	Dungeness crab (*Cancer magister*)	Avoid disturbance of migration to shallow-water nursery areas	Case-by-case basis
	Salmonids	Avoid disturbance of salmon in river delta	Case-by-case basis

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
South Pacific/ Sacramento	Chinook salmon (*Oncorhynchus tshawytscha*)	Avoid the following alterations during upstream migration and to the spawning habitat: turbidity, reduced water quality, disruption of migration, effects of sedimentation on spawning and incubation, physical disturbance of spawning habitat	October-April
North Pacific/ Portland	Dungeness crab (*Cancer magister*)	Avoid disturbance to juvenile crabs, particularly in navigation channels	15 April-1 December
		Avoid entrainment of crabs. When possible use of clamshell dredge is recommended, and hopper dredging is limited to period September-February	February-September
	Juvenile salmonids	Avoid disturbance of juvenile fishes	15 April-1 December
	Eagles and anadromous fish	Avoid impacts to eagles and fish when present	December-September (variable)
Seattle	Juvenile salmonids	Avoid impacts from turbidity and entrainment	15 March-15 June
	Dungeness crab (*Cancer magister*)	Avoid critical life history period (Puget Sound)	15 June-30 November
		Avoid entrainment (Grays Harbor)	June
	Bald eagle (*Haliaeetus leucocephalus*)	Avoid nesting pairs, particularly feeding areas	1 January-15 August (where eagles present)
	Pandalid shrimp	Avoid turbidity-mediated impacts	1-30 September

(Continued)

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Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
North Pacific/ Alaska	Pacific herring (*Clupea harengus pallasi*)	Avoid physical disturbance of spawning habitat	April-May
	Adult and juvenile salmonids	Avoid turbidity-mediated channel blockage of migratory pathways	15 April-15 May
		Avoid physical disturbance of nearshore feeding habitat of smolts	20 March-15 May and 10 July-30 August
		Avoid entrainment of smolts by hydraulic dredge	Conditional: operation of suctionhead only on or within proximity of the bottom
Walla Walla	Anadromous fishes Chinook salmon (*Oncorhynchus tshawytscha*) Steelhead trout (*Oncorhynchus mykiss*)	Avoid turbidity impacts on fishes and benthic organisms	Year-round except 1 January-1 March
		Avoid impacts to fishes as a result of dredging of chemically contaminated sediments	
		Avoid entrainment of juvenile fishes	
		Avoid physical and turbidity-induced channel blockage to migrating adults and juveniles	
		Avoid impact on local aquatic food chain through the loss of benthic organisms	
North Central/ St. Paul	Migratory waterfowl	Avoid disturbance of nesting and feeding in vicinity of sanctuary	1 October-winter freeze-up

(Continued)

(Sheet 12 of 14)

Table 1 (Continued)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
North Central/ Buffalo	Smallmouth bass (*Micropterus dolomieui*) White bass (*Morone chrysops*) Channel catfish (*Ictalurus punctatus*) Walleye (*Stizostedion vitreum vitreum*) Northern pike (*Esox lucius*) Sauger (*Stizostedion canadense*) Steelhead trout (*Oncorhynchus mykiss*) Coho salmon (*Oncorhynchus kisutch*) Brown trout (*Salmon trutta*)	Avoid interference with migration and/or spawning activities	Generally September-May or February-June
Chicago	Steelhead trout (*Oncorhynchus mykiss*) Coho salmon (*Oncorhynchus kisutch*) Chinook salmon (*Oncorhynchus tshawytscha*)	Avoid channel blockage during migratory runs of young and adults	Year-round except between 1 June and 20 July
		Avoid physical disturbance of spawning habitat	
	Steelhead trout and coho salmon (Burns Waterway, Indiana)	Avoid channel blockage during downstream migratory runs of smolts	15 March-15 June
		Avoid channel blockage and water quality problems (dissolved oxygen and turbidity) which may impact upsteam migratory runs of adults	15 July-15 September (restricted to 12-hr daylight maximum and no night dredging)
Detroit	Water quality (general), spawning fishes	Avoid potential adverse impacts from turbidity, sedimentation, and physical disturbance on water quality and fish spawning	31 March-1 July and 31 August-1 November/ December (variable)
	Nesting waterfowl	Minimize disturbance of nesting activities proximal to disposal sites	Variable as above

(Continued)

(Sheet 13 of 14)

Table 1 (Concluded)

Division/District	Resource(s) of Concern	Reason(s) for Restriction	Nondredging Period(s) (Dates Inclusive)
North Central/ Detroit (Continued)	Terns	Avoid disturbance of nesting activities on dredged material disposal areas	30 April-15 August
	Salmonids	Avoid potential adverse impacts from turbidity, sedimentation, and physical disturbance of migration	31 March-1 July and 15 September-1 November

(Sheet 14 of 14)

PART II: FRAMEWORK FOR DETERMINING THE NEED FOR SEASONAL RESTRICTIONS ON DREDGING AND DISPOSAL PROJECTS

10. A simplified method for conducting an efficient, consistent, and objective review of proposed Federal and permit dredging and disposal projects is described by the flowchart shown as Figure 1. The method requires three distinct review levels to determine the need for applying seasonal restrictions on a proposed project. A decision to proceed with the proposed project or to approve the action without seasonal restrictions is possible on all three levels; a decision to apply seasonal restrictions is possible only on Review Level 3 following the conclusion of activities on Levels 1 and 2. Each review level differs from the others in terms of the kinds of activities performed and the amount of time required to complete the activities. A Level 1 or 2 review requires the compilation of project-specific information, which can be concluded in a few hours to a few days. Level 3 reviews could require intermittent action by Corps personnel and others over a period of a week or more. The review levels also differ in terms of objectivity. Conclusions of Level 1 and Level 2 review are based largely on objective comparisons between proposed dredging/disposal project schedules and operations, on one hand, and biological facts about the proposed project location and specific qualitative or quantitative criteria on the other. Review Level 3 is a relatively more subjective action.

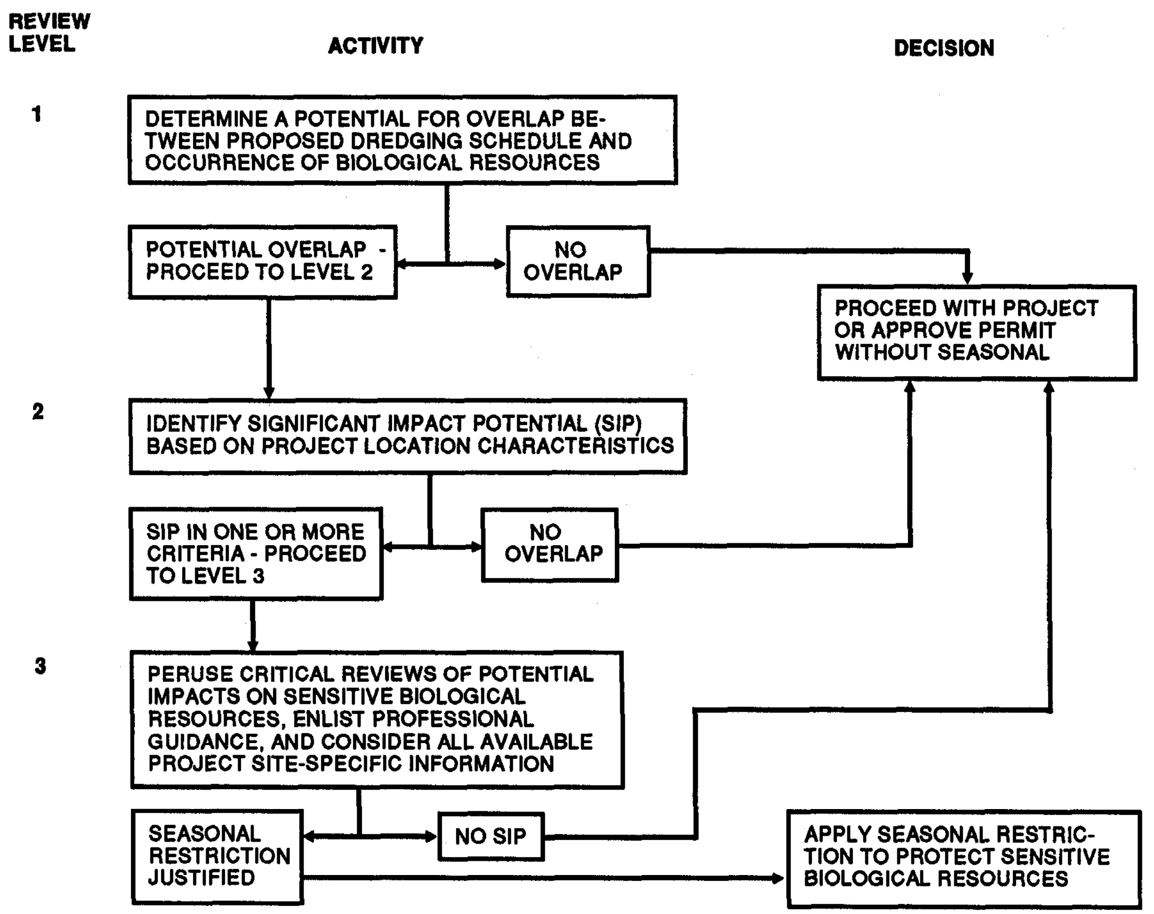

Figure 1. Schematic flowchart describing the sequence of activities for determining the need for seasonal restrictions

Review Level 1: Determination of Potential Overlap Between the Proposed Dredging/Disposal Schedule and the Occurrence of Biological Resources

11. Using information provided by (a) the Federal dredging/disposal project documentation or the permit dredging/disposal application, (b) resource maps and inventories, (c) knowledge of the project area, and (d) coordination activities during review involving other Federal and State agencies, determine the times of the year that the proposed project area is used by important organisms for breeding, foraging, rearing, or migratory route. This may include any or all life history stages of the organism(s) considered. Display the results using a time-line for each species and/or life history stage (Figure 2a).

12. Based on the information used above, determine the occurrence of the proposed dredging/disposal activity and display the results using a time-line (Figure 2b). By superimposing the time-lines for each species and/or life history stage and the project activity, potential problem (overlap) periods can be identified (Figure 2c).

13. When overlap of organism(s) and project activity occurs, two options exist. The first is to modify the dredging/disposal schedule to avoid the overlap period, if possible. The second option is to proceed to Review Level 2.

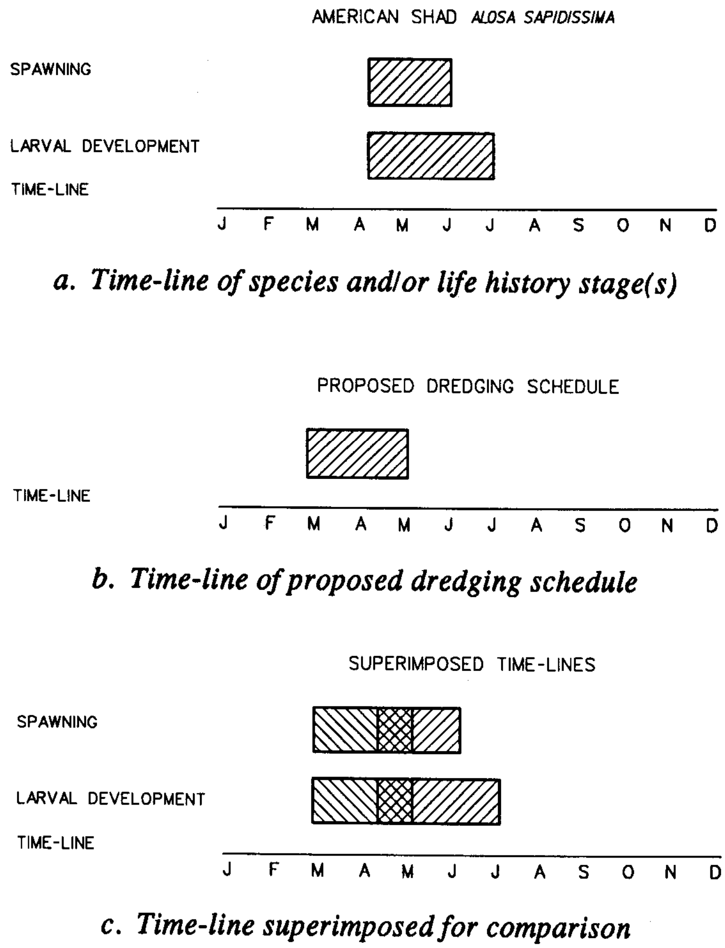

Figure 2. Suggested presentation of results of Review Level 1 time-lines

Review Level 2: Identifying Significant Impact Potential Based on Characteristics of the Proposed Project Location

14. Using information provided by the Federal dredging/disposal project documentation or in the permit dredging/disposal application and other available sources of site-descriptive information (physical, chemical, and biological characteristics), review the six descriptive project criteria in the Level 2 worksheet (Table 2) and place a check in column A or B to indicate whether each criterion is a concern.

15. If subsequent examination of the completed worksheet indicates there are no checks in column A boxes, the project may proceed or be approved without seasonal restrictions. If one or more of the descriptive project criteria are determined to be of concern, as checked in column A boxes, proceed to Review Level 3. This condition suggests that there is a possibility of significant impact potential (SIP) relevant to the characteristics of the project area. This is a "red flag" condition suggesting that a closer look should be taken before proceeding with the project or before approving the permit without seasonal restrictions.

16. The rationale for selection of the six criteria and instructions for their interpretation follow the description of the review process. The use of a 500-m "buffer zone" reflects the generalized "worst-case" area-of-influence described around typical dredging operations (see Dredge comparisons, paragraphs 78-80).

Review Level 2 Criteria

17. The six criteria included in the Criteria Worksheet (Table 2) were constructed mainly from information presented in the sections of this report dealing with:

a. Physical and chemical environmental alterations affected by dredging and disposal operations.

b. Critical reviews and conclusions regarding the principal biological issues affecting seasonal regulation of dredging and disposal activities.

18. These criteria are conservative and reflect the general uncertainty affecting decisions about almost any complex environmental issue. For each criterion, the discussion that follows will address the rationale for its selection, the standards used in the Review Level 2 criteria worksheet, and the biological issue(s) to which it applies.

Significant biological resources in the vicinity of the proposed project

19. ***Rationale for selecting this criterion.*** A concern about important benthic biological resources occurs if they inhabit the project location within the boundaries of the buffer zone and if sediment dispersion characteristics favor sedimentation. Planktonic life history stages tend toward greater susceptibility to elevated suspended sediment concentrations than do motile life history stages. Planktonic stages may also be susceptible to entrainment by hydraulic dredges. Planktonic biological resources are given special consideration when conditions indicate a possibility for their transport within the areas of the most concentrated suspended sediments or within the entrainment field of a hydraulic dredge. Bird, turtle, and mammal nesting colonies are also of considerable importance within a project area since noise levels as well as general activity near a colony can cause stress.

20. ***Worksheet standards.*** The presence or absence standard for nonnektonic biological resources as well as for bird-nesting colonies in the vicinity of the proposed project is determined by their occurrence within the 500-m buffer zone.

Table 2
Review Level 2 Criteria Worksheet

Criteria	Column A	Column B
Significant biological resources in the vicinity of the proposed project	☐ Significant biological resources located ≤500 m of the proposed project	☐ Significant biological resources located >500 m from the proposed project
Project area morphometry	☐ ≤500 m of continuous open water between the dredge and a fastland shoreline	☐ >500 m of continuous open water between the dredge and a fastland shoreline
Project area sediment dispersion characteristics	☐ Conditions favoring sedimentation	☐ Conditions favoring dispersion
Natural or dredged channel in the vicinity of the proposed project used as migratory route	☐ Channel present ≤500 m from the proposed project	☐ Channel absent or located >500 m from the proposed project
Natural suspended sediment maxima (seasonal) in the vicinity of the proposed project	☐ Concentrations of suspended sediments beyond 500 m from the dredge expected to exceed natural suspended sediment concentration maxima for that season at the project location	☐ Concentrations of suspended sediment not expected to exceed natural concentration maxima
Dredged material contamination status	☐ There is a "reason to believe" that there is a significant contaminant present	☐ Uncontaminated

21. ***Applicable biological issues.*** The concerns are for the egg, larval, juvenile, and adult stages (demersal and planktonic) of important fishes and shellfishes and for nesting colonies of birds, turtles, and mammals.

Project area morphometry

22. ***Rationale for selecting this criterion.*** Substantial evidence indicates that dredging operations produce a suspended sediment concentration field that is contained within very limited spatial boundaries (see Dredge comparisons, paragraphs 78-80). This is a critical point relevant to this and to three of the four criteria remaining to be discussed. This criterion is intended to ensure that fishes in the vicinity of the dredging project have a "safety" corridor through which the suspended sediment field can be bypassed if necessary.

23. ***Worksheet standards.*** The standards are very simply judged by estimating the continuous open-water distance between the proposed dredging location and a shoreline. Continuous open water may be defined by a line woven among a complex of islands situated between the proposed project and a shoreline or by a straight line through uninterrupted aquatic habitat. If an estimated distance of at least 500 m does not exist at a given project site, then consideration of appropriate restrictions could be justified.

24. ***Applicable biological issues.*** Motile juvenile and adult fishes are considered by this criterion. As the critical review of these issues indicated, there is no conclusive evidence to support a position that the movement of fishes is or is not impacted by dredging-induced suspended sediment fields. The maintenance of a corridor of water at or near background suspended sediment concentrations beyond a 500-m buffer zone reflects a conservative "no significant impact potential" position.

Project area sediment dispersion characteristics

25. ***Rationale for selecting this criterion.*** Certain significant benthic biological resources are sensitive to increased rates of sedimentation. A significant impact potential exists when conditions favoring sedimentation occur in areas inhabited by important benthic biological resources.

26. ***Worksheet standards.*** A qualitative judgment about conditions favoring sedimentation or dispersion would be required when applying this criterion. Factors contributing to the judgment should include current and salinity conditions.

27. ***Applicable biological issues.*** The principal concerns of the criterion on sediment dispersion characteristics are the demersal eggs of some important fishes and shellfishes and the adult life stages of shellfishes.

Natural or dredged channel in the vicinity of the proposed project

28. ***Rationale for selecting this criterion.*** A widely accepted professional opinion among fishery biologists is that some important fishes and shellfishes, anadromous fishes in particular, immigrate to their upstream spawning grounds or emigrate to coastal waters via dredged or natural channel corridors. These biologists believe that the occurrence of a dredging project within or adjacent to a channel might interfere with the upstream or downstream migrations of these fishes or shellfishes. The critical reviews did not identify any technical information that can be used to either support or refute this opinion. Therefore, this criterion is intended to respect the possibility that the concern is real.

29. ***Worksheet standards.*** Readily available bathymetric (depth contour) information about the proposed project and adjacent areas can be used to determine the presence of a channel in the 500-m dredging buffer zone. A channel is simply either present or absent. There is no information available to identify the relationship between channel characteristics (e.g., configuration,

cross-sectional profile, depth, etc.) and the channel's use as a fish migration corridor; however, site-specific data may exist and can be used to make decisions.

30. ***Applicable biological resources.*** This criterion is primarily intended to protect immigrating adult anadromous fishes.

Natural suspended sediment maxima in the vicinity of the proposed project

31. ***Rationale for selecting this criterion.*** Quoting directly from Cairns (1968):

> Since aquatic organisms survive (or at least enough survive to perpetuate the species) temporary exposure to rather high concentrations of suspended solids, it seems best to relate suspended solids standards to the variations and conditions to which the aquatic species have become adjusted. This would of course mean that the standards would be based on stream conditions rather than fixed arbitrary standards.

This criterion is based on the realization that species are well adapted to the range of environmental conditions in a given habitat. In the case of estuarine/marine environments, a major environmental factor is suspended sediment concentration. This criterion simply allows for a comparison of dredge-induced suspended sediment levels with those of the ambient conditions in a given area.

32. ***Worksheet standards.*** The standards for this criterion are based on the ambient (background) seasonal suspended sediment concentration maximum (SSSCM) for the project area. The SSSCM value may have to be estimated rather than directly measured. Its inclusion in the list is based on the opinion that it is fundamental to any attempt to construct a method for arriving at socially responsible resource management decisions about seasonal restrictions on dredging projects. Cairns (1968) made this additional statement qualifying his call for standards quoted above:

> Since stream flow and other characteristics vary from day to day, this would require both continual monitoring of the water quality of each basin with appropriate information feedback to those using the stream. This is now possible with computer programming of water quality for a particular river.

It is believed that the criterion should be more semiquantitative than quantitative. The important questions are:

a. Is the dredging project scheduled during a time period where SSSCM values occur at the proposed project location?

b. Does the suspended sediment concentration field, produced during the dredging project, present a significant addition to the SSSCM in its spatial and temporal dimensions?

33. If the conclusion is that the dredging-induced suspended sediment concentration field is expected to be greater than the SSSCM in its spatial and temporal dimensions within 500 m of the proposed dredging location and "sensitive life stages" of "significant biological resources" inhabit the area within the buffer zone, then imposition of a seasonal restriction is justified.

34. If the conclusion is that the dredging-induced suspended sediment concentration field within 500 m of the proposed dredging location is not expected to represent a significant increase in comparison with the spatial and temporal dimensions of the SSSCM of the proposed dredging location, then do not impose a seasonal restriction.

35. ***Applicable biological issues.*** The concept of comparisons between expected dredging-induced suspended sediment concentrations and the SSSCM is intended to protect the eggs and larval life stages of fishes and shellfishes and the adult life stages of sessile shellfishes.

Dredged material contamination status

36. ***Rationale for selecting this criterion.*** Observations made primarily during controlled laboratory studies and explanations offered by theories about an animal's performance capacity under natural and pollution-induced stresses lend support to the contention that animals exhibit greater sensitivity to contaminated suspended sediments than to uncontaminated ones.

37. ***Worksheet standards.*** This criterion is evaluated through standard procedures for testing the suitability of dredged material for open-water disposal.

38. ***Applicable biological issues.*** The criteria worksheet reflects the conclusions in the published technical literature that egg, larval, and juvenile stages of fishes and shellfishes are sensitive to contaminated sediments in suspension. Significant susceptibility of motile adult fishes and shellfishes to contaminated suspended sediments is not supported by the technical literature.

Review Level 3: Subjective Evaluation of Potential Impacts of Project on Sensitive Biological Resources

39. Use the critical reviews of potential environmental alterations and their effects on biological resources provided in the next section to become familiar with the important issues. If project constraints and resources allow, enlist professional assistance from experts familiar with the project area or the resource(s) in question. Options for resolving contentious issues are available and involve processes by which experts on various aspects of the issue in question are consulted as a group and asked to make recommendations concerning the issue.

PART III: APPROACHES TO INTERAGENCY COORDINATION AND COOPERATION IN ADDRESSING THE SUBJECT OF SEASONAL RESTRICTIONS

40. This section is devoted to describing examples of interagency coordination and cooperation in dealing with seasonal restrictions on dredging/disposal projects. The examples used are all basically similar, in that discussions and decision-making processes include the participation of personnel from all parties having a formal review authority over dredging and disposal activities (State, Federal, and/or private), including biologists at both managerial and technical levels. Inherent in this philosophy is the realization that a constructive dialogue between parties is of the utmost importance if any mutually agreeable solutions to conflicts can be found. Each example discussed here involves the use of committees, either standing committees, which meet periodically to discuss project permit applications (and discuss potential concerns), or technical resolution committees, which meet on an ad hoc basis to discuss specific issues.

41. The first type of committee is an example of a means of continued open communication between agencies that have permit comment and review authority. The second type of committee exemplifies a means by which unresolved issues can be discussed and recommendations can be made to reach an acceptable operational decision, and can/should include outside expertise in its deliberations. In some cases, specific unresolved problems encountered during discussion by a standing committee can logically lead to the establishment of a resolution committee.

Project Advisory Standing Committee

42. The US Army Engineer District, Norfolk, sponsors what can be called project review committees for the State of Virginia (organized by both the Operations and Planning Divisions of the Norfolk District). The purpose of these committees is to keep all pertinent State and Federal agencies having project/permit review authorities informed about projects being planned or conducted and to report on the status of completed projects. The committee itself does not, however, make decisions, but makes recommendations to the decision-maker--the Corps. One of these committees, sponsored by the Dredging Management Branch, is known as the Federal Dredging Management Committee and is herein described. The committee is composed of representatives from the following agencies: US Fish and Wildlife Service, National Marine Fisheries, Virginia State Water Control Board, Virginia Marine Resource Commission, and the Virginia State Council on Environmental Quality. In addition, the District invites representatives from other agencies that serve in an advisory capacity for one or more of the above-mentioned agencies. An example is the inclusion of personnel from the Virginia Institute of Marine Sciences, which consults for the State Marine Resource Commission.

43. The committee meets on a semiregular basis (2- to 3-month interval) to discuss projects divided into four categories: (a) projects in the early planning stages, (b) projects in final planning stages, ready for permit action, (c) previously approved projects being initiated or waiting commencement, and (d) ongoing or completed projects. This four-category approach allows for commenting on any particular project through all stages of development and provides an opportunity to discuss scheduling as it might relate to seasonal restrictions. All parties involved are kept informed on the details of each project, thereby allowing for discussion of potential problems in a timely manner. Again, the underlying philosophy is open communication and discussion with all parties.

44. Details of projects in the planning-stage category can be modified to reflect concerns expressed about environmental impacts to resources. Discussion of projects that are near-ready for permit action allows for final comment or action by the committee (in essence, a second chance to review the project and make suggestions or modifications). Discussion of projects being initiated

serves as a status report designed to keep everyone informed, while discussion of ongoing or completed projects allows for review of any problems encountered or the results of monitoring efforts during a particular project. This last aspect of reporting on completed projects is the most attractive aspect of the process, in that it provides a means by which the committee can be made aware of actual problems encountered during operations. The Corps, as well as other members of the committee as a group, can then incorporate these experiences into the decision-making process of future projects. In this way, the committee as a group learns from experience. There is no substitute for being directly involved or informed about the "nuts and bolts" of a project.

45. Two aspects of the standing committee approach to evaluating dredging/disposal projects make it attractive as a coordination device. The semipermanency of the committee makeup, both in terms of the agencies represented and the personnel involved, allows for expediency and smooth operation, while the incorporation of a follow-up review of projects allows for learning by experience, which can lead to a better understanding of the environment and the effects of human activities.

Technical Issue Resolution Committee

46. A short-term or one-time committee has been employed in at least two cases for the purpose of addressing specific issues related to seasonal restrictions. The committee is charged with discussing potential consequences of a project and/or formulating recommendations about a specific issue. This type of committee is an appropriate mechanism for addressing unresolved or minimally understood issues. In each case, discussed below, makeup of the committee was similar to that used for a standing committee in that in-house and outside technical expertise, as appropriate, were represented. In addition, the committee's responsibility was not to render a decision about a project but only to make recommendations concerning the issue in question, based upon available technical information.

47. Examples of such a committee include: (a) a workshop sponsored by the Baltimore District to evaluate the potential for entrainment of larval oysters by hydraulic cutterhead dredges and (b) a panel called by the Seattle District to examine options for avoidance and mitigation of dredging-induced mortality of dungeness crabs. In the first case, the committee was asked to help address a controversial issue, whereas in the second case, the committee was asked to render advice that could be used to alleviate or minimize impacts on a particular resource. A very important additional benefit of both committees was the actual review of available information about the subject at hand, which served to focus attention on the areas where information is most lacking. The review of state-of-the-art knowledge can also be used to identify needs for future monitoring studies.

Oyster entrainment workshop

48. In August 1985 the Baltimore District, in conjunction with the WES, sponsored a technical workshop to discuss the topic of potential entrainment of oyster larvae by hydraulic cutterhead dredges (American Malacological Union 1986). This issue reflected a special concern, voiced by the Maryland Department of Natural Resources (MDNR). The MDNR was concerned that the activity of hydraulic dredges "near" productive oyster bars during the spawning season represented a significant impact on the oyster larval population. The view of the Corps was that dredging did not represent a significant impact on the oyster larval population.

49. The primary objective of this workshop was to attempt to resolve this issue by bringing together independent experts on various aspects of oyster biology and dredging procedures so that a more thorough understanding of the issue could be formulated and recommendations made as to how to proceed. The committee consisted of authorities on oyster biology, oyster fisheries, and dredging operations, who were asked to address these questions: do hydraulic cutterhead dredges

entrain significant numbers of larval oysters, and if so, to what extent will this reduce oyster production in Chesapeake Bay?

50. The workshop consisted of oral presentations and discussions by various participants, in the categories of opposing views on whether restrictions were valid based on available knowledge, aspects concerning the physicochemical alterations around a working dredge, characteristics of water circulation in Chesapeake Bay, and various aspects of oyster biology pertinent to the topic of larval entrainment. Following this overview of existing knowledge, participants were asked to: (a) determine if a practical numerical model of larval entrainment could be formulated, and if so, to define the components of such a model; (b) determine if such a model could be field verified; and (c) propose methods by which a dredging operation could be monitored in order to restrict or modify operations.

51. In the case of this particular issue, the workshop resulted in a set of recommendations (Carriker et al. 1986) concerning how agencies involved in this issue (as well as any other) should work together in a spirit of cooperative coordination, as opposed to an adversarial atmosphere, and a proposed simple numerical model of oyster entrainment based on the present level of understanding of oyster larval biology. An alternative model of oyster larval entrainment was also presented and discussed.

52. For the purpose of this description, the particulars of both recommendations are irrelevant. What is important to remember is the nature of the committee itself and the associated validity of the resulting recommendations. The ultimate goal is to come to a resolution of the issue being discussed (pro or con) so that a more informed, technically supported decision can be made.

Crab study panel

53. During August and September 1984, the Seattle District sponsored a panel of experts to recommend options for avoidance and mitigation of dungeness crab losses in Grays Harbor, Washington (Pearson 1985). The formation of the study panel reflected uncertainty expressed by the Seattle District as to the optimal course of action in this case. The objectives of the panel were: (a) to study the options for avoidance and mitigation of crab losses and make recommendations about the best option or combination of options to alleviate the problem and (b) to review the current state-of-the-art knowledge concerning dungeness crab biology and make suggestions regarding future studies.

54. The panel consisted of authorities on crab biology, crab fisheries, and dredging operations, and met on two occasions. The approach to these meetings involved the preparation, by a coordinating staff, of working papers (a compilation of available information) that were distributed to panel members before each meeting and were used as a starting point for panel discussions. Topics of discussion included options for avoidance of crab losses and mitigation, evaluative criteria for these plans, and considerations of cost factors.

55. During the course of the first meeting, the panel selected the most promising options for further consideration. From these preliminary discussions, the coordination staff compiled additional information on the best options for further consideration during the second meeting. The result was a final report concerning recommendations for further studies.

Summary

56. In summary, the approach prescribed here for dealing with unresolved issues involving seasonal restrictions is based on (a) the realization that cooperation and coordination with regulatory agencies is essential to reaching a meaningful understanding on an issue and (b) conclusions and/or recommendations must be based on technically sound information. To this end, personnel involved with permit applications and issues of seasonal restrictions must educate themselves on the underlying biological factors of any issue and rely on sound technical information

and not "gut" reaction. This not only allows for a better understanding of the ecosystem and the impacts imposed by human activities, but also for challenging ill-founded restrictions from an intelligent standpoint.

PART IV: PHYSICAL AND CHEMICAL ENVIRONMENTAL ALTERATIONS ASSOCIATED WITH DREDGING AND DISPOSAL OPERATIONS

57. This section provides brief descriptions of the types of dredging and disposal operations commonly employed and the degree of physical and chemical environmental alterations associated with each. Each dredging/disposal operation is briefly described, followed by discussions on the degree to which each type of operation affects suspended sediment, dissolved oxygen, and chemical mobilization. This information, along with knowledge of the response of organisms to these alterations (as provided in Part V), can be used to evaluate the potential for project-related impacts. When evaluating the likelihood of impacts, a number of other project-related factors should be considered, including the total amount of material to be removed, whether material is removed from continuous or disjunct sections of a channel, and the estimated duration of activity.

Types of Dredging and Disposal Operations

58. The following brief descriptions of various dredging and disposal operations are condensed primarily from Barnard (1978); US Army Engineer, Headquarters (1983); Raymond (1984); and Richardson (1984). In the case of dredging, only the three most commonly used dredge types are discussed. The practice of barge or hopper overflow is also briefly discussed. Open-water disposal is discussed in the sense of how it compares to that of a typical dredging operation (e.g., differences in magnitude of alterations).

Bucket or clamshell dredge

59. The bucket or clamshell dredge consists of a bucket operated from a crane or derrick mounted on either a barge or operated from shore. The sediment removed by the bucket is at nearly its in situ density. The material is usually placed in barges for transportation to a disposal area. Depending on the type of material being removed, barge or scow overflow may be practiced in an effort to increase the effective amount of heavy material retained. Although the dredging depth is practically unlimited, the deeper the depth, the lower the production rate. In addition, the clamshell dredge usually leaves an irregular, cratered bottom. This dredge type is used extensively for removing relatively small volumes of material (tens to thousands of cubic meters), particularly in spatially restricted areas around docks and piers, although larger dredges with large-volume buckets are increasingly being used for major new work projects, in part because it is easier to break into virgin material.

Hydraulic cutterhead dredge

60. The hydraulic cutterhead dredge (also commonly called pipeline dredge) consists of a rotating cutterhead positioned at the end of a ladder that excavates the bottom sediment. The excavated material is picked up through a suction pipe and transferred by means of a centrifugal pump to a designated disposal area through a pipeline as a slurry. The typical solids content of the slurry is 10 to 20 percent by weight. The typical cutterhead dredge is swung in a arc from side to side as the dredge is stepped forward on pivoting spuds at the stern of the dredge. Operation of this type of dredge is nearly continuous, and production rates are generally high. Cutterhead dredges are used extensively for removal of large quantities of material during channel excavation and maintenance operations with relatively short distances to the disposal site (1.5 to 5 km).

Hopper dredge

61. A hopper dredge consists of one or two dragarms (trailing suction pipe) and attached dragheads mounted to a barge or self-propelled ship. As the dredge moves forward, bottom sediment is hydraulically lifted through a dragarm and temporarily stored in hopper bins in the ship's

or barge's hull. The hoppers are either emptied by dumping the dredged material through doors in the bottom of the ship's hull or by pumping the material through a pipeline. Because solids consist of only 10 to 20 percent of the pumped slurry, a hopper loading operation often includes the overflow of turbid water out of the top or side of the hopper, the intent of which is to increase the effective amount of heavy sediment material retained in the hopper. Hopper dredges are used primarily in areas of heavy ship traffic or rough water.

Barge and hopper overflow

62. The practice of barge or hopper overflow was reviewed by Palermo and Randall (1990) and involves the deliberate filling of either a barge or hopper above its capacity in an attempt to increase the solids content of material with the barge or hopper. In all cases the object of overflow is to increase the economic loading (maximum volume) of material carried away from the dredging site with each load. Overall, economic loading is possible only with high-density (weight) materials such as coarse sand or consolidated clay.

Open-water disposal

63. Under certain circumstances, dredged material excavated during maintenance dredging operations may be placed within designated open-water or side-channel areas. During cutterhead dredge operations, dredged material is dispersed through the end of the pipeline either above water or submerged at an angle of 0 to 90 deg (1.6 rad) relative to the water surface. During hopper dredge operations, dredged material is released through doors at the bottom of the hopper. Sediment may also be dredged mechanically and transported and disposed from dump barges or scows. Depending on the operation, the solids content of the dredged material can range up to 40 percent by weight.

Beach, nearshore, and shore disposal

64. Beach disposal operations are another type of disposal event during which dredged material is dispersed either directly onto a beach or into an adjacent surf zone or littoral drift zone, from which material will eventually migrate to the beach or shoreline.

Sources of Turbidity and Suspended Sediment Fields

65. The following brief discussions of dredge-specific suspended sediment fields, unless otherwise noted, are taken from reviews by Barnard (1978); Raymond (1984); Hayes, Raymond, and McLellan (1984); Hayes (1986); Lunz and LaSalle (1986); Havis (1988a); McLellan et al. (1989); and LaSalle (1990). Information on reducing sediment suspension caused by dredging operations, although not discussed here, can also be found in the same references, as well as Huston and Huston (1976). Suggestions for reducing sediment dispersion during open-water disposal can be found in Schubel et al. (1978).

Bucket or clamshell dredging

66. Turbidity generated by a bucket dredge operation comes from four major sources: sediment suspension occurring upon bucket impact and withdrawal from the bottom, loss of material from the top and sides of a bucket as it is pulled up through the water column, spillage of turbid water out of the bucket when it breaks the water surface, and inadvertent spillage of material during barge loading or intentional overflow operations intended to increase a barge's effective load. A number of variables can affect the quantity of material suspended by the dredge, such as sediment type, bucket size and type (open or enclosed), volume of sediment dredged, hoisting speed, and hydrodynamic conditions at the dredging site.

67. Measurements of suspended sediment fields around bucket dredging operations summarized in Table 3 and in additional studies by Sustar, Wakeman, and Ecker (1976) and Nakai (1978)

Table 3
Spatial and Temporal Characteristics of Suspended Sediment Fields During Bucket Dredging Operations

Location	Suspended Sediment Field Characteristics	Reference
San Francisco Bay, California	Nearfield concentrations of total suspended sediments were 21-282 mg/L.	Williamson and Nelson (1977)
San Francisco Bay California	Suspended sediment concentrations in the water column 50 m downstream from the dredge were generally less than 200 mg/L and averaged 30-90 mg/L relative to background concentrations outside the plume of approximately 40 m/L. The visible plume was about 300 m long at the surface and approximately 450 m long at a bottom depth of 10 m.	US Army Engineer District, San Francisco (1976)
Lower Thames River Estuary, Connecticut	Maximum suspended sediment concentrations of 68, 110, and 168 mg/L at the surface, middepth (3 m), and near-bottom (10 m), respectively, were noted within 100 m downstream. These maximum concentrations decreased very rapidly to the background levels of 5 mg/L within 300 m at the surface and 500 m near the bottom. Fine-grain sands and silts.	Bohlen and Tramontano (1977)
Lower Thames River Estuary, Connecticut	Suspended sediment concentrations adjacent to the dredge were 200-400 mg/L and approached background within approximately 700 m. Major perturbations were confined within 300 m of the dredge. Fine-grain sands and silts.	Bohlen, Cundy, and Tramontano (1979)
New Haven Harbor, Connecticut	Suspended sediment plume (defined by transmissometer readings) was a well-defined small-scale feature extending over a distance of approximately 1,000 m downstream.	Gordon (1973)
Patapsco River, Maryland	Suspended sediment concentrations 22 m downstream from the dredging operation were 30 mg/L at near-bottom depths of 10 m relative to background water column concentrations of approximately 10 mg/L or less.	Cronin et al. (1976)
Japan	Maximum suspended sediment concentrations 7 m downstream from the dredging operation ranged from 150 to 300 mg/L (defined using turbidity measurements) relative to background levels of less than 30 mg/L. These levels decreased by 50 percent at a distance of 23 m. Turbidity near the surface was generally lower than levels at middepth or near the bottom. Fine-grained.	Yagi, Koiwa, and Miyazaki (1977)
St. Johns River, Florida	Sediment resuspension caused by bucket dredges showed that the plume downstream of a typical bucket operation may extend approximately 1,000 ft (300 m) at the surface and 1,500 ft (450 m) near the bottom. The average suspended sediment concentrations of all samples collected within 800 ft (240 m) of the dredge along upper water column and near-bottom transects were approximately 106 and 134 mg/L, respectively. Silts.	Raymond (1983)
St. Johns River, Florida	A comparison of suspended sediment concentrations from open and enclosed bucket dredge operations showed considerable reductions in suspended sediment concentrations in the upper water column (>50 percent) but increases in concentrations in the lower water column (>50 percent) due to "shock" waves created by the closed bucket. Silts.	Hayes, Raymond, and McLellan (1984)
Thames River Estuary, Connecticut	The composition of material suspended by the dredge indicates that variations are similar to those produced by local storm events. Storm events affect a significantly larger area and display a higher frequency of occurrence than that characterizing typical dredging schedules. Both storm events and dredges increase particulate organic carbon concentrations and bias the material composition in favor of the inorganic fractions. Sands and silts.	Bohlen, Cundy, and Tramontano (1979)
Patuxent River, Maryland	Total suspended sediment concentrations measured before, during, and after dredging. Downstream stations showed increases of 42 mg/L (4,000 ft) and 25 mg/L (2,000 ft); upstream stations, 2 mg/L (1,000 ft) and 12 mg/L (2,000 ft). Postdredging concentrations returned to predredging levels of 34-44 mg/L within 19 days. Clayey-silt.	Onuschuk (1982)

suggest a general pattern for the spatial extent of sediment suspension. A typical operation can produce a downstream turbidity plume that extends 300 m at the surface and 500 m near the bottom (depth dependent). Maximum suspended sediment concentrations in the surface plume are generally less than 500 mg/L above ambient in the immediate vicinity of the operation and decrease rapidly with distance due to settling and dilution of the material. Average surface water column concentrations are generally less than 100 mg/L, while near-bottom concentrations are usually higher. The visible surface plume usually dissipates within an hour or two after the operation ceases, depending upon the type of material being dredged.

68. Comparisons of open and watertight or enclosed bucket types indicate that surface-water suspended sediment concentrations may be reduced by 30 to 70 percent when using an enclosed bucket (Barnard 1978; Hayes, Raymond, and McLellan 1984). Near-bottom concentrations, however, were shown to be increased by as much as 50 to 70 percent due to the effect of the enclosed bucket as it descends through the water. A shock wave of water precedes the bucket and serves to suspend loosened material prior to impact.

69. Bohlen, Cundy, and Tramontano (1979) described bucket dredge-induced suspension as primarily a near-field phenomenon representing a relatively small-scale perturbation within an estuary. Sediment suspended by a dredge is likened to a small-scale storm that begins very suddenly, increases the concentrations and modifies the quality of suspended sediment fields compared with undisturbed conditions, and produces a turbidity plume that decays very rapidly following the reduction of energy required to suspend and maintain sediments in suspension.

Hydraulic cutterhead dredging

70. The turbidity generated by a hydraulic cutterhead dredge operation (exclusive of disposal) is primarily due to the action of the cutterhead and is directly related to the type and quantity of the material being disturbed, but not picked up by the suction. A number of operational variables may also influence suspended sediment levels around the cutterhead, including the rate of cutterhead rotation, vertical thickness of the dredge cut, and the swing rate of the dredge. Additional turbidity is often generated by leaky pipeline connections.

71. Measurements of suspended sediment fields around cutterhead dredge operations summarized in Table 4 and in additional studies (Markey and Putnam 1976; Smith et al. 1976; Sustar, Wakeman and Ecker 1976; Koba and Shiba 1983; Kuo, Welch, and Lukens 1985) demonstrate that elevated levels of suspended sediments appear to be restricted to the immediate vicinity of the cutterhead with little suspension in surface waters. Maximum levels of suspended sediment, on the order of tens of grams per liter, are confined to within 3 m above the cutterhead and decline exponentially to the water's surface. Near-bottom levels may be on the order of hundreds of milligrams per liter at distances of up to a few hundred meters laterally from the cutterhead. Upper-water column levels are usually quite low or even undetectable, depending on water depth. Suspended sediment levels generated by the cutterhead apparently increase exponentially as the thickness of the cut, rate of swing, and cutterhead rotation increase. In addition, levels of suspended sediments increase around the cutterhead as successive cuts are made until an equilibrium between suspension and settling is established. Current speeds above 2 fps (0.6 m/sec) associated with ebb and flood tidal action can, however, significantly affect the suspended sediment field by propelling materials higher into the water column. High-velocity ebb tides have the greatest effect.

Hopper dredging

72. The turbidity generated by a hopper dredge operation (exclusive of disposal) is due primarily to the dredge's dragheads as they are pulled through the bottom sediment and, more visibly, by the discharge of sediment-laden water when hopper overflow is practiced.

Table 4
Spatial and Temporal Characteristics of Suspended Sediment Fields During Hydraulic Cutterhead Dredging Operations

Location	Suspended Sediment Field Characteristics	Reference
Mobile Bay, Alabama	Suspended sediment concentrations around a 61-cm cutterhead dredge were elevated above background levels only within 1.5 m of the bottom. Near-bottom concentrations of up to 125 mg/L occurred approximately 300 m in front of the cutterhead; a value of 336 mg/L was recorded 30 m behind the cutterhead. Silts and clay.	Barnard (1978)
Corpus Christi Ship Channel, Texas	Near-bottom suspended sediment concentrations within 2 m of the cutterhead of a 69-cm cutterhead dredge ranged from background levels to 580 mg/L measured 73 m to the side of the dredge. Fine-grained.	Huston and Huston (1976)
Yokkaichi Harbor, Japan	Concentrations of suspended sediment under low-current conditions near the cutterhead of a 61-cm cutterhead dredge ranged from 2 mg/L to 31 g/L, 1 mg/L to 16 g/L, and 1 mg/L to 4 g/L at distances of 1, 2, and 3 m above the cutterhead, respectively, relative to background levels. Average concentrations decreased exponentially to the water surface. Fine-grained.	Yagi et al. (1975)
James River, Virginia	Average suspended sediment concentrations over a 4-day period within 800 ft (200 m) of a 46-cm cutterhead dredge ranged from background levels to 282 mg/L above background. Levels greater than 100 mg/L above background were restricted to the lower water column while average values for flood and ebb tide for the upper water column were 11.5 mg/L and 37.5 mg/L, respectively. Clay.	Raymond (1984)
Savannah River, Georgia	Suspended sediment concentrations within 1,600 ft (480 m) of a cutterhead dredge were generally less than 200 mg/L in the lower water column and less than 100 mg/L and 50 mg/L in the middle and upper water column, respectively. Silts.	Hayes (1986)
Imari and Osaka Bays Japan	Suspended sediment concentrations, above background, measured around three dredges. Mean values of suspended sediment levels for upper and lower water column ranged from 2-6 mg/L at 50 m, 2-3 mg/L at 100 m, and 2 mg/L at 200 m. Maximum levels never exceeded 72 mg/L above background. Clay.	Koba (1984)

73. Measurements of suspended sediment fields around hopper dredge operations summarized in Table 5 and in Smith et al. (1976) show that elevated suspended sediment levels are primarily due to hopper overflow (near-surface water) and the action of the draghead (near-bottom water). Suspended sediment levels may be on the order of tens of grams per liter near the hopper overflow and on the order of a few grams per liter or less near the draghead. Suspended sediment levels in the near-surface plume decrease exponentially with distance from the dredge. However, a plume may occasionally be perceptible at distances in excess of 1,200 m, largely because this type of dredge is in constant motion.

74. A comparison of hopper dredge operations with and without overflow (Hayes, Raymond, and McLellan 1984) indicated that, in the absence of overflow, a turbidity plume was not encountered in the surface or middepth levels and that the maximum suspended sediment level in the near-bottom plume was 70 mg/L.

Barge and hopper overflow

75. The process of overflow usually involves the intentional loading of sediment-laden water beyond the capacity of the barge or hopper in an effort to increase the effective solids content within the vessel. The basic assumption behind the practice is that, given time, heavier sediment particles will settle out within the barge or hopper, and relatively low-solids water can be displaced by additional material. In the case of barges, the material simply flows over the gunnel. In hopper dredges, multiple inflow pipes and hopper compartments and baffles act to reduce the flow rate of water and sediments after entering the vessel, thereby enhancing settling. Overflow from hopper dredges comes from a point farthest from the inflow, after most of the heavier sediment particles have settled out.

76. Measurements of suspended sediment fields around hopper dredge overflow operations have been reported by Barnard (1978); Hayes, Raymond, and McLellan (1984); Hayes (1986); Havis (1988a); McLellan et al. (1989); and Palermo and Randall (1990). Similar data are available on barge overflow activities associated with cutterhead (Benson, in preparation) and bucket dredge operations (Payonk, Palermo, and Teeter 1988; Palermo, Teeter, and Homziak 1990).

77. Overflow events can increase suspended sediment levels throughout the water column. Hopper dredge operations with overflow, as previously mentioned for Grays Harbor, Washington (Hayes, Raymond, and McLellan 1984), can increase levels by 200 mg/L at the surface and 1,000 mg/L near the bottom. Turbidity plumes can extend from the dredge by as much as a few hundred meters at the surface and a few thousand meters along the bottom. Overflow tests (fine silts and clays) associated with a cutterhead operation in Mobile Bay, Alabama (Benson, in preparation) showed maximum levels of 60 mg/L for the surface and 6,000 mg/L along the bottom, with most levels falling below these. A study of overflow associated with a bucket dredge operation (silts and clays) in the Cape Fear River, North Carolina (Payonk, Palermo, and Teeter 1988) reported maximum levels of suspended sediment (above background) of 87 mg/L for surface and 162 mg/L along the bottom at a distance of 100 m downstream. Overall, overflow events can increase suspended sediment concentrations by as much as 100 mg/L at the surface and 1,000 mg/L along the bottom, with suspended sediment plumes extending a few hundred meters downstream for cutterhead and bucket dredges (stationary operations) and a few thousand meters for hopper dredges (mobile operations).

Dredge comparisons

78. The suspended sediment fields around the three commonly used dredge types can be described in general terms of the range of concentrations at surface and bottom and the range of spatial dispersion away from the dredge (Table 6). Overall, the cutterhead dredge seems to produce the least amount of suspended sediments, followed by the hopper dredge without overflow, and finally the bucket dredge (Wakeman, Sustar, and Dickson 1975; Hayes, Raymond, and

Table 5
Spatial and Temporal Characteristics of Suspended Sediment Fields During Hopper Dredging Operations

Location	Suspended Sediment Field Characteristics	Reference
San Francisco Bay, California	Suspended sediment concentrations in the near-bottom plume were usually less than a few grams per liter, while the upper near-surface plume concentrations ranged from several hundred milligrams per liter away from the dredge to several grams per liter adjacent to the dredge overflow. Both plumes extended 700 m or more down current. Silty clay.	US Army Engineer District, San Francisco (1976)
Saginaw Bay, Lake Huron, Michigan	Near-surface suspended sediment concentrations ranged from 100 g/L at the dredge to near 80 mg/L 1,200 m downstream. Overflow concentrations decreased exponentially with distance from the dredge.	Pollack (1968)
Thimble Shoal, Chesapeake Bay	Near-surface suspended sediment concentrations ranged from near 2 g/L at the dredge overflow to near 20 mg/L 850 m downstream. Concentrations decreased exponentially with distance from the dredge.	JBF Scientific Corp. (1974)
Grays Harbor, Washington	In the absence of hopper overflow, the suspended sediment plume was restricted to the near-bottom waters and appeared to be 60 m wide and 1,100 m long with maximum concentrations of 70 mg/L. In the presence of hopper overflow, the surface plume appeared to be 60 m wide and 1,200 m long with concentrations reaching 857 mg/L at 30 m behind the dredge. The near-bottom plume appeared to be greater than 120 m wide and 2,600 m long with concentrations as high as 891 mg/L and 460 mg/L at 30 and 60 m behind the dredge, respectively. Silty clay.	Hayes, Raymond, and McLellan (1984)

McLellan 1984; Raymond 1984). The spatial extent of the plume is greatest for bucket and hopper dredges in both surface and bottom waters. Comparing dredges operating in clay, however, Herbich and Brahme (as cited in Raymond 1984) reported that sediment suspension was similar for a hopper dredge without overflow and a cutterhead dredge, while a bucket dredge could produce about 2.5 times as much sediment suspension. Observed differences among dredge types are largely attributable to the mode of operation of the two general types of dredges (mechanical and hydraulic) as well as operational parameters. Regardless of the type of dredge used, a number of dredge modifications and operational adjustments have been suggested to control sediment suspension (see Barnard 1978, Raymond 1984).

Table 6
General Characteristics of Suspended Sediment (SS) Fields Around Three Commonly Used Dredge Types

	SS Concentrations, mg/L		SS Plume Length, m	
Dredge Type	**Surface**	**Bottom**	**Surface**	**Bottom**
Cutterhead	0-150	≤500	0-100	≤500
Hopper*	0-100	≤500	0-700	≤1,200
Bucket	0-700	≤1,100	100-600	≤1,000

Sources: Barnard 1978, Raymond 1984, and McLellan et al. 1989.
* Without overflow.

79. Worst-case suspended sediment fields for each dredge type are shown in Figure 3, including a hopper dredge operation with overflow. A generalized worst-case field was described by LaSalle (1990) as having suspended sediment concentrations ≤500 mg/L at distances ≤500 m from the dredge, with maximum concentrations generally restricted to the lower water column within 50 to 100 m, decreasing with distance.

80. Bohlen, Cundy, and Tramontano (1979) described the field around a bucket dredge as a near-field phenomenon and compared it to that produced by storm surges. They pointed out that a single storm surge can introduce baywide as much as 2.5 times the quantities of sediment resuspended by a dredge into the water column, that a storm affects the entire body of water, and that major storms can occur up to four times per year. A dredge, on the other hand, affects a much smaller portion of a given system. Dredging operations have also been compared to other anthropogenic activities that can generate suspended sediments, including shrimp trawling, in the range of 500 to 600 mg/L (Schubel, Carter, and Wise 1979), and ship traffic (Slotta et al. 1973), which affects a given channel year-round.

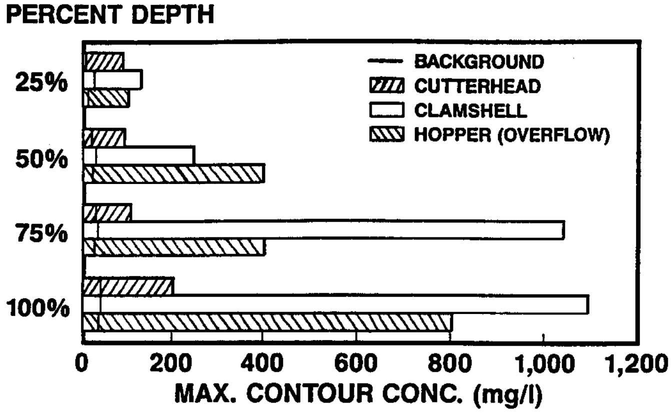

Figure 3. Maximum total suspended sediment concentrations measured around three commonly used dredge types (redrawn from Havis 1988a, data taken from McLellan et al. 1989)

Open-water dredged material disposal

81. Several factors may affect the characteristics of turbidity plumes associated with open-water disposal operations, including the discharge rate, character of the dredged material slurry (e.g., sediment character, solids content), water depth, hydrodynamic regime, and the discharge configuration (e.g., below or above water, parallel or angled).

82. Levels of suspended sediment in the water column above the fluid mud layer (>200 g/L) generally range from a few tens to a few hundred milligrams per liter. In general, the quantity of material suspended in the upper water column is from 1 to 5 percent of the amount released (see Truitt 1986). Concentrations decrease rapidly with distance downstream and laterally from the discharge point. Barnard (1978) discusses the effect of the various factors controlling plume characteristics and describes a simple model for predicting plume character. Schubel et al. (1978) field-tested the model and provided additional insight into disposal plume behavior under various hydrologic regimes.

Dissolved Oxygen Reduction

83. Dredging-induced dissolved oxygen (DO) reduction in the water column around a dredge or disposal operation is a direct consequence of the suspension of anoxic sediment material and results in the creation of both chemical and biological oxygen demands. Available information about DO depletion around dredged material disposal operations (Biggs 1970; US Fish and Wildlife Service 1970; May 1973; Slotta et al. 1973; Westley et al. 1973; Smith et al. 1976; Wright, Mathis, and Brannon 1978) suggests that within the disposal plume, levels in DO reach 0, but that DO depletion is often difficult to detect from background away from the plume. Dissolved oxygen depletion around dredging operations has been reported at varying levels (Brown and Clark 1968; Slotta et al. 1973; Markey and Putnam 1976; Smith et al. 1976; Sustar, Wakeman, and Ecker 1976; US Army Engineer District, Portland 1982; Lunz, LaSalle, and Houston 1988; Houston, LaSalle, and Lunz 1989).

84. Dissolved oxygen levels around a bucket dredge were depleted in a highly industrialized channel in New York (Brown and Clark 1968) by 16 to 83 percent in the middle to upper water column and by as much as 100 percent in near-bottom waters. A cutterhead dredge operation in Grays Harbor, Washington (Smith et al. 1976) caused periodic reductions in bottom water DO by as much as 2.9 mg/L (about 35 percent of ambient). Reduction in DO (1.5 to 3.5 mg/L, 25 to 30 percent of ambient) associated with a hopper dredge operation in a tidal slough in Oregon (US Army Engineer District, Portland 1982) was restricted to slack-water conditions in the lower third of the water column. When tidal flow resumed (within 2 hr), DO levels increased by as much as 2 mg/L under floodwater conditions. The effect of a bucket dredge operation on DO in the Hudson River, New York (Lunz, LaSalle, and Houston 1988; Houston, LaSalle, and Lunz 1989), was minimal (generally <0.2 mg/L) in the immediate vicinity of the dredge during dredging. Percent DO saturation on a baywide basis was also minimally reduced (by 10 percent) corresponding to a drop in DO of about 1 mg/L. Other studies have reported minimal or no measurable reduction in DO around dredges (Slotta et al. 1973; Markey and Putnam 1976; Sustar, Wakeman, and Ecker 1976).

85. A review of the processes associated with DO reduction (Lunz and LaSalle 1986) suggested that DO demand is a function of the amount of suspended sediment being placed into the water column, the oxygen demand of the sediment, and the duration of resuspension. While the high levels of suspended sediment (tens of grams) associated with the fluid mud layer of disposal operations may reduce DO levels substantially, the relatively low levels of suspended sediment associated with a cutterhead operation are predicted to have a relatively small effect on DO (Lunz and LaSalle 1986).

86. Efforts to predict DO depletion around dredging operations (Lunz and LaSalle 1986; Lunz, LaSalle, and Houston 1988) have been based on the assumption that any reduction in DO is the

direct consequence of oxidation of suspended reduced constituents in anoxic sediments. Two basic models of DO reduction have been developed, differing only in the kinds of material causing DO demand and the relative time interval over which the reactions are expected to occur. One model was based on levels of total organic carbon (TOC) and an estimated relationship with volatile solids, which can act over hours or days, while a second model was based on measurements of the most commonly encountered reactive chemical components found in estuarine sediments (ferrous iron and free sulfides), which would create an immediate oxygen demand.

87. Both models predicted minimal DO depletion (from 0.5 to 1.9 mg/L) around a bucket dredge operation. Results of actual monitoring of DO around a dredge (Houston, LaSalle, and Lunz 1989) showed minimal (<0.2 mg/L) immediate DO depletion in the immediate vicinity of the dredge, which was difficult to detect relative to background fluctuations of as much as 1 mg/L. Baywide monitoring, however, showed slightly greater levels of DO depletion (measured as percent saturation) by as much as 10 percent (about 1 mg/L). Predicted values based on iron and sulfur levels appeared to be a better predictor of immediate reductions while those based on TOC appeared to better predict baywide conditions. Given the relatively low levels of suspended material generated by dredging operations and considering factors such as flushing (not accounted for in either model), DO depletion around these operations should be minimal.

Chemical Contaminant Mobilization

88. The release of naturally occurring (nutrients, sulfides, iron, etc.) and industrially derived (metals, organohalogens, pesticides, etc.) substances by the suspension of sediments during dredging or dredged material disposal is of particular interest when contaminated sediments are known or suspected to be involved. As with DO reduction, most available information comes from studies of dredged material disposal (reviewed by Lee et al. 1975; Chen et al. 1976; Burks and Engler 1978; Gambrell, Khalid, and Patrick 1978; Stern and Stickle 1978) which indicate that the levels are generally low and that releases are highly transient. The processes involved with the fate of these compounds have been studied and Lunz and LaSalle (1986) provide a condensed review of the information concerning these processes and associated controlling factors.

89. In general, most metals and other compounds are generally not readily available in a soluble form in the water column, but only as part of an iron complex or in association with organic matter and clays (Windom 1972, 1976; May 1974). Reduced iron, once oxidized during suspension of sediment material, actively scavenges metals and other compounds. As these compounds settle to the bottom, they are again reduced under anoxic conditions. Similar associations of chlorinated hydrocarbons with silts, clays, and organic detritus also limit their availability as soluble forms. The effect of release of nutrients such as nitrogen and phosphorus via sediment suspension varies. Both beneficial (stimulated photosynthesis) and detrimental (excessive biological growth, ammonia toxicity) effects have been documented in aquatic ecosystems.

90. Direct measurements of chemical releases around dredging operations are reported in Smith et al. (1976), Wakeman (1977), Tramontano and Bohlen (1984), and Havis (1988b). Wakeman (1977) reported significantly higher concentrations of four metals in San Francisco Bay. Average concentrations (filtered water) above background in surface samples were 0.16 mg/L for zinc, 0.01 mg/L for lead, 0.03 mg/L for chromium, and 0.01 mg/L for nickel; bottom sample levels were 0.05 mg/L for chromium and 0.08 mg/L for nickel. Copper and mercury levels were unaffected by dredging. Smith et al. (1976) observed elevated concentrations of sulfides (range 3.9 to 1,690 µg/L) in Grays harbor, with levels generally <50 µg/L. Tramontano and Bohlen (1984) observed elevated quantities of phosphate, ammonia, and silica in near-bottom waters within 180 m of the dredge and elevated amounts of manganese and copper within 12 m; cadmium levels were unaffected. While concentrations of these compounds in the immediate vicinity of the dredge (3 to 6 m) exceeded background levels by as much as 2 to 9 times, the absolute levels remained low: 17.1 µM/L for ammonia, 1.0 µM/L for phosphate, 14.5 µM/L for silica, 0.4 µM/L for manganese, and

0.1 µM/L for copper. These authors also suggested that, when compared with background levels of the whole system, dredging operations would increase these constituents by no more than 2 percent for ammonia, 1 percent for phosphate, 0.5 percent for silica, 0.1 percent for manganese, and 0.2 percent for copper. Studies of release of contaminants associated with dredging of contaminated sediments at three sites (Havis 1988b) serve to provide some comparative information (Table 7). Relative levels for chemical species common between sites were similar.

Table 7
Average Concentrations (mg/L, Absolute Values) of Selected Contaminants Released During Dredging of Contaminated Sediments

	Compound									
Site	Zn	Pb	Cu	Cd	Hg	As	Cr	Ni	Mn	Fe
Black Rock Harbor, Connecticut	0.03	0.003	0.01	0.001	0.0001	0.01	0.001	0.01	0.12	0.70
Duwamish River, Washington	0.02	0.007	0.002							
James River, Virginia	0.002	0.009	0.01	0.003						

Source: Havis 1988b.

PART V: REVIEWS OF AVAILABLE LITERATURE REGARDING ENVIRONMENTAL IMPACTS TO BIOLOGICAL RESOURCES

91. This section provides summaries of the available technical literature concerning impacts to biological resources from physical and chemical environmental alterations associated with dredging and disposal activities. Major classes of alterations include suspended sediments, sedimentation, chemical release, dissolved oxygen reduction, channel blockage, and entrainment. Major categories of biological resources include fishes, shrimps and crabs, shellfishes (e.g., oysters and clams), benthic assemblages, a miscellaneous group that includes threatened or endangered species (e.g., marine mammals, sea turtles), and colonial-nesting birds. To a large extent, these categories include those resources which the seasonal restrictions are designed to protect.

92. Of the alterations listed above, the bulk of available information comes from studies of effects of suspended sediments, sedimentation, and to some degree, entrainment. For this reason, information on these classes of alterations is presented under each of the major categories of resources, except endangered species, for which there is a unique set of alterations. Each section on a given class of alteration includes a brief summary that includes general conclusions and recommendations, when appropriate. For the remaining classes of alterations, discussions are based largely on the potential effects of these alterations and available information on the degree of each. It should be noted that these discussions are presented not as exhaustive reviews of all available information but for the purpose of providing pertinent information relative to important issues. Morton (1977), Allen and Hardy (1980), Profiles Research and Consulting Groups, Inc. (1980), and Kantor (1984) provide similar reviews on these topics. More extensive information on a given topic can be found in review papers which, when available, are indicated as such in the text.

93. An attempt has been made to separate discussions of various effects by life history stage, when possible. The reason for this approach is to emphasize the realization that the early life history stages of most organisms are generally more sensitive or susceptible to environmental alterations than are adult stages. Therefore, it is important to consider effects on each life stage when reviewing a project.

Effects of Environmental Alterations on Fishes

Fish - general comments

94. The ultimate survival and strength of a given year class of fishes are largely determined by events that occur during egg and larval developmental stages. The relative success or failure of transitions through critical phases, such as at the time of first extrogenous feeding (i.e. deriving nutrition from planktonic prey rather than yolk reserves) or during metamorphosis from larval to juvenile form, can be influenced by extant environmental conditions. In comparison with juvenile and adult fishes, egg and larval stages seem generally more sensitive to stress of whatever origin (Rosenthal and Alderdice 1976). Also, because of their dependence on local hydrodynamic conditions for transport into and out of project areas and limited or nonexistent escape capabilities, egg and larval stages have been asserted to be more susceptible to the effects of unfavorable environmental conditions than motile juvenile and adult life history stages (Auld and Schubel 1978). As a result, resource agency concerns over detrimental effects of dredging and disposal operations have focused on how environmental alterations affect egg and larval stages of marine and estuarine species. In addition, concerns regarding anadromous fishes involve (a) the supposition that turbidity fields constitute a barrier to migration of adult and juvenile fishes and (b) a concern about entrainment of eggs, larvae, and juveniles by hydraulic dredges.

95. Two basic reproductive patterns occur among fishes, which are important considerations in relation to dredging operations. Many coastal or estuarine-dependent species produce pelagic eggs (free-floating, unattached or in gelatinous masses) which, depending on their specific gravities,

may occur at various levels in the water column from surface to bottom. Potential impacts on pelagic eggs may therefore be related to both spatial distributions of suspended sediments and duration of exposure to specific concentrations. In the case of most estuarine-dependent species, however, this life stage occurs in offshore water away from most dredging and disposal operations. Other fish species, including anadromous species, produce demersal, nonbuoyant eggs that may either adhere to substrates at the spawning site, and therefore remain in place for short to extended periods prior to larval hatching and release, or are carried downstream in bottom currents. In addition to the problem of exposure duration, demersal eggs may be subject to burial by accumulated deposited sediments and/or entrainment by suction dredges.

Fish - suspended sediments

96. ***Discussion.*** The causal factors by which suspended sediments affect eggs and larval fishes are complex. Cairns (1968) provided a detailed summary of these factors, which include direct mechanical abrasion of egg and larval surficial membranes, reduction of available light in the water column, and sorption of contaminants carried by the sediments. Indirect effects of elevated suspended sediments may also be of consequence. Examples include interference with feeding behavior of visually oriented larvae or delayed development resulting in asynchronous occurrences of larvae and their prey. Very little is known of the importance of synergistic effects resulting from combinations of causal factors, or how physical features of the suspended particles such as size or angularity contribute to the effects observed. Stresses caused by chemical, physical, or biological conditions may be manifested in chronic rather than acute biological responses (Sherk 1972), further complicating the determination of detrimental effects.

97. Given the above complexities, it is difficult to draw clear conclusions from published studies on effects of suspended sediments on fish eggs and larvae. Because they do not produce accurate quantitative mortality estimates, information critical to assessing project impacts (Dovel 1970), field studies have yielded largely inconclusive results (e.g., Flemer et al. 1967). The dual constraints of logistics and the inability of field designs to isolate effects of experimental factors have relegated meaningful studies to the laboratory.

98. A meaningful summary of laboratory results is hindered by the lack of standardization in experimental protocol (e.g., selection of test concentrations, exposure durations, or suspensions of natural versus processed sediments) and equipment used to maintain sediments in suspension. A review of studies evaluating suspended sediment effects on fish eggs and larvae is provided by Schubel, Williams, and Wise (1977). A number of pertinent references on this issue are products of investigations in the upper Chesapeake Bay system, particularly in connection with striped bass spawning grounds in the vicinity of the Chesapeake and Delaware Canal (Schubel and Wang 1973; Auld and Schubel 1978; Priest 1981; Morgan, Rasin, and Noe 1983). Table 8, although not a comprehensive compilation, represents a sample of the results of relevant investigations.

99. Laboratory studies have focused on three aspects of responses of fish eggs and larvae to elevated suspended concentrations. Effects have been demonstrated at various levels of suspended sediment concentrations in terms of (a) percent successful hatch of eggs, (b) time elapsed between fertilization and hatching, and (c) percent survival of larvae after known durations of exposure. For example, Schubel, Williams, and Wise (1977) concluded that striped bass eggs (semibuoyant) can tolerate very high suspended sediment levels ($\geq$1,000 mg/L) for periods of many hours. Similarly, Kiorboe et al. (1981) reported that embryonic development and hatching of herring (*Clupea harengus*) were unaffected by either long-term exposure (10 days) to low to moderate concentrations (5 to 300 mg/L) of suspended silt or short-term exposure (2 hr) to higher concentrations (500 mg/L) of silt.

100. There is some indication that larval stages may be more sensitive to elevated suspended sediment concentrations than are eggs of the same species. For example, Auld and Schubel (1978)

Table 8
Results of Experimental Determinations of Effects of Suspended Sediments on Various Life History Stages of Fishes (Modified from Priest 1981)

Species	Stage	Suspended Sediment Concentration, mg/L	Exposure Duration	Type of Sediment	Degree of Effect	Reference
Yellow perch White perch Striped bass Alewife	Eggs	500	Not stated	Natural	No significant effect on hatching success; some delay in time to hatching noted in samples at ~100 mg/L (for all species)	Schubel and Wang (1973)
White perch		50-5,250		Natural (fine)	No significant effect on hatching success; definite delay in development at ≥1,500 mg/L	Morgan, Rasin, and Noe (1983)
Striped bass		20-2,300		Natural (fine)	No significant effect on hatching success definite delay in development at ≥1,300 mg/L	
Atlantic herring		5-300 500	10 days 2 hr	Natural Natural	No significant effect on development or hatching success	Kiorboe et al. (1981)
Blueback herring		50-5,000	Not stated	Natural (fine)	No significant effect on hatching success at all test concentrations	Auld and Schubel (1978)
Alewife American shad Yellow perch						
White perch					Significant effect on hatching success at 1,000 mg/L, but not at lower concentrations	
Striped bass					Significant effect on hatching success at 1,000 mg/L, but not at lower concentrations	
White perch	Larvae	1,626-5,380	24-48 hr		15-49% mortality	Morgan, Rasin, and Noe (1983)
Striped bass		1,557-5,210	24-48 hr		20-57% mortality	
Yellow perch		50-1,000	4 days	Natural	Survival significantly reduced at ≥500 mg/L	Auld and Schubel (1978)
Striped bass		50-1,000	2-3 days		Survival significantly reduced at ≥500 mg/L	
Alewife		50-1,000	4 days		Survival significantly reduced at ≥100 mg/L	
Spot	Adult	13,090 68,750	24 hr	Artificial Natural	LC_{10}	Sherk, O'Connor, and Neumann (1975)
Striped killifish		23,770 97,200		Artificial Natural		
Mummichog		24,470		Artificial		
Atlantic silverside		580		Artificial		

(Continued)

Table 8 (Concluded)

Species	Stage	Suspended Sediment Concentration, mg/L	Exposure Duration	Type of Sediment	Degree of Effect	Reference
Bay anchovy	Adult	2,300	24 hr	Artificial	LC_{10}	Sherk, O'Connor, and Neumann (1975)
White perch		9,970		Natural		
		3,050		Artificial		
Striped bass	Subadult	4,000	21 days	Natural		Peddicord and McFarland (1978)
Cunner	Adult	133,000	12 hr	Natural (silt)	Median tolerance limit	Rogers (1969)
		100,000	24 hr			
		72,000	48 hr			
Mummichog		300,000	24 hr		No mortality	
Sheepshead minnow		300,000			<30 percent mortality	
Cunner		100,000			Median tolerance limit	
Stickleback		52,000			Median tolerance limit	

reported that striped bass, yellow perch, and American shad larvae were less tolerant than eggs of these respective species at equivalent experimental suspended sediment concentrations. This trend may be attributable to loss of protection provided by the chorion (outer egg membrane) upon hatching of the larvae (Boehlert 1984). Additionally, many fish larvae are highly dependent on the epidermis as a respiratory surface. Adhesion of sediment particles to the epidermis may exert a smothering effect, although adhesion was noted by Boehlert (1984) only at concentrations above 1,000 mg/L, which is well above that found in dredging operations. Priest (1981) critically reviewed the literature pertaining to effects of total suspended solids on fish eggs. He concluded that for the four species considered, the only effect caused by the highest levels of suspended solids expected at a dredging operation was a slight delay in time to hatching. Lethal concentrations sufficient to produce a 50-percent mortality in laboratory experiments of larvae of the studied species were far in excess of levels characteristic of dredging operations.

101. Mechanical abrasion has been identified by Cairns (1968) as an important suspended sediment effect, yet little attention has been given to differential effects of sediments of different particle characteristics. The premise here is that delicate surficial membranes such as gills or the epidermis of larval fishes are particularly susceptible to abrasive damage. Several lines of evidence support this view. Rogers (1969) reported that processed sediments (highly angular incinerator residues) were much more toxic to experimental fishes than naturally weathered estuarine sediments. Coarse sediments were also shown to exert greater detrimental effects on fish survival rates than fine sediments of equal concentration. Boehlert (1984) compared the effects of natural, weathered estuarine sediments to those of sharp, angular Mount St. Helens volcanic ash on yolk sac larvae of Pacific herring (*Clupea harengus pallasi*). Severe abrasion and puncture damage of larval epidermal membranes were observed via light and electron microscopy at volcanic ash concentrations of 1,000 mg/L, whereas comparable effects were evident for natural sediments only at concentrations at or above 4,000 mg/L (all larvae exposed to experimental concentrations for 24 hr). Although larvae did not show significant mortality at any experimental concentration (up to 8,000 mg/L), observed effects could represent sublethal stress that may contribute to later mortality.

102. Although juvenile forms might be suspected to be somewhat less tolerant of elevated suspended sediment concentrations than adults, the literature is sparse and incomplete on the direct physical effects of elevated suspended sediment concentrations on juvenile stages. Wallen (1951) exposed both adults and juveniles of a number of freshwater fish species to a wide range of silt-clay suspensions, all of which were well above concentrations found under typical dredging conditions. While results for juveniles were not presented separately, he concluded that direct effects of turbidity due to montmorillonite (hydrous aluminum silicate) type silt-clay is not a lethal condition and seldom produced observable symptoms in juvenile or adult fishes. Sherk, O'Connor, and Neumann (1975), working with juvenile Atlantic menhaden (*Brevoortia tyrannus*), determined that a lethal concentration producing 10-percent mortality (LC_{10} value) of 1,540 mg/L was obtained after a 24-hr exposure to Fuller's earth (a combination of clay and siliceous material). Jeane and Pine (1975) compared the effects of elevated turbidities at dredging sites characterized by suspension of fine versus coarse sediments through in situ bioassays using juvenile chinook salmon. No significant mortality was observed among juveniles exposed to fine sediment suspensions. Exposure to coarse sediments led to mortalities, but these were greater at stations away from the actual dredging site. This led the authors to suggest that toxic contaminants or some other artifact confounded the results.

103. Determination of direct physical effects of elevated suspended sediment concentrations on adult fishes lends itself to both field and laboratory examination. As a result, a considerable body of relevant literature exists (Table 8). Interpretation of this literature, however, is limited by the lack of standardization among experiments and differing experimental protocols. The most widely used approach employs basic bioassays in which fishes are exposed to incremental concentrations

of suspended sediments until some lethal concentration is determined, generally that which produces a 10- or 50-percent mortality (LC_{10} or LC_{50}) after a specified period (e.g., Sherk, O'Connor, and Neumann 1975; O'Connor, Neumann, and Sherk 1976; Peddicord and McFarland 1978). Another common approach is to measure threshold concentrations of suspended sediments above which a given species is adversely affected.

104. A widely referenced study on 16 species of freshwater fishes (Wallen 1951) found lethal turbidity thresholds to be equal to or greater than 16,500 mg/L following exposure durations ranging from 3.5 to 17 days. Behavioral signs of stress for most species were not apparent at suspended sediment concentrations under 20,000 mg/L. Peddicord and McFarland (1978) determined that rainbow trout showed no significant mortality after 22 days at concentrations below 2,000 mg/L, and 95-percent survival occurred at concentrations approaching 4,300 mg/L. Although under less controlled conditions, other studies have exposed caged specimens to in situ levels of suspended and deposited sediments at actual dredging sites (Ingle 1952, Ritchie 1970), reporting little or no detrimental effect.

105. Several workers have employed histological preparations of gill tissues to demonstrate effects of elevated suspended sediments. Ritchie (1970) found no evidence of gill pathology in specimens of 11 estuarine fish species prior to and after exposure to dredging conditions. Sherk, O'Connor, and Neumann (1975), however, found disrupted gill tissue and increased mucus production in white perch exposed to sublethal suspended sediment concentrations (650 mg/L).

106. ***Summary.*** Based on studies conducted to date (Table 8), all life stages of estuarine-dependent and anadromous fish species appear to be fairly tolerant of elevated suspended sediment concentrations. In all probability, fishes that use naturally turbid habitats as spawning and nursery grounds are adapted to and highly tolerant of elevated suspended sediment concentrations and, in some cases (e.g., striped bass), correspond to periods of greatest ambient suspended sediment levels. Such conditions would not be expected to prevail at a dredge site for sufficient lengths of time to merit special concern; however, disposal operations may be of such duration to cause concern. These investigators suggested that a conservative safe level at which no impact would be anticipated would be 500 mg/L. A strong case can be presented that a 1,000 mg/L-limit would also be acceptable.

Fish - sedimentation

107. ***Discussion.*** A number of fish species deposit demersal (often adhesive) eggs that generally remain in place on the bottom until larval hatching. There is a concern that heightened sedimentation rates in project areas may lead to smothering of these eggs. Morgan, Rasin, and Noe (1983) studied effects of sediment deposition on white perch (*Morone americana*) eggs and showed that hatching was not significantly affected by sediment layers 0.45 mm thick or less (egg diameter approximated 0.9 mm). Sediment layers 0.5 to 1.0 mm thick resulted in over 50-percent mortality, and a deposited sediment layer 2.0 mm thick caused nearly 100-percent mortality.

108. Naqvi and Pullen (1982) reviewed the impacts of beach nourishment projects on fishes, suggesting that these operations may have significant effects on deposited eggs of spawning species. Parr, Diener, and Lacy (1978), however, observed that beach nourishment apparently did not affect subsequent spawning activity of grunion (*Leuresthes tenuis*). Juveniles and adults of practically all fishes are sufficiently mobile to avoid burial due to increased sedimentation rates or prolonged exposures to suspended sediments at a dredging site. Fishes generally return shortly after the disturbance ceases (Courtenay et al. 1972; Parr, Diener, and Lacy 1978; Reilly and Bellis 1978, 1983; Courtenay, Hartig, and Loisel 1980; Holland, Chambers, and Blackman 1980). The major impact on these stages is the potential loss of benthic food resources (see paragraphs 140-146).

109. ***Summary.*** Given the potential deleterious effects of sedimentation on demersal eggs of fishes, precautions should be considered (including the option for seasonal restrictions) if the path of dredging activities lies within an identified fish spawning area. This is especially important in water characterized by slack-water or low-flow conditions where high sedimentation rates will occur following suspension of sediments by dredging or disposal activities. Under certain conditions (e.g., when coarse sand is involved), effects of sedimentation may be confined to a much smaller area.

Fish - entrainment

110. ***Discussion.*** Both demersal and pelagic fish eggs and larvae are susceptible to entrainment by suction dredges due to their inability to escape the suction field around the intake pipe (see McNair and Banks 1986). Demersal eggs and larvae may be picked up directly with the sediment, while pelagic forms may be drawn in from the surrounding water column. Of particular concern is the potential entrainment of fishes exemplified by migrating salmon fry. Depending on the species, fry may be present at various times of the year and throughout the water column or restricted to different portions of it (usually the upper portions), thereby affecting the potential for entrainment.

111. Arseneault (1981) reported rates of entrainment for chum and pink salmon fry by hydraulic dredges to be within the range of 0.04 to 0.00004 percent of the total migration in the Fraser River, Canada, in 1981. While these estimates appear very low, the operation of the dredges involved was modified to avoid migrating fry by restricting operations to water depths in excess of 10 to 15 ft (3 to 4.6 m) and by restricting the activation of suction pumps to within 5 ft (1.5 m) from the bottom. Mortality of entrained fry was, for all practical purposes, 100 percent, since the majority of fry were buried by sediment in the disposed material, while the remainder suffered abrasion of external and gill surfaces. Boyd (1975) reported 98.8-percent mortality for fry entering a pipeline dredge and observed that eggs entrained by both pipeline and hopper dredges were killed by the action of the dredge.

112. Entrainment rates for several species of fishes were reported by Armstrong, Stevens, and Hoeman (1982) for Grays Harbor, Washington, and by Larson and Moehl (1990) for the mouth of the Columbia River, Oregon and Washington (Table 9). Armstrong, Stevens, and Hoeman (1982) reported species-specific rates ranging from 0.001 to 0.135 fish/cubic yard, which included several commercially important species. Both large (up to 234 mm) and small fishes were entrained; however, comparisons with trawl data indicated that many species were apparently capable of avoiding the dredge. Larson and Moehl (1990) reported average rates of entrainment, ranging from 0.001 to 0.38 fish/cubic yard of material dredged. The only species consistently entrained at moderate levels (range 0 to 18.89 fish/cubic yard) was the bottom dwelling sand lance (*Thaleichthys pacificus*). Entrainment of commercially important salmonids was reported only for a single species (chum salmon) at low levels in Grays Harbor (Table 9).

113. ***Summary.*** Although reported entrainment rates for fishes (in the northwest) are low, the potential for entrainment may increase if operations occur during migration periods and work is in heavily used narrow-channel habitats. For example, Arseneault (1981) recommended that, for riverine habitats in the Canadian Pacific Northwest, suction dredging should be permitted only in water that is at least 15 ft (4.6 m) deep during the migratory period of salmonid fry and that the cutterhead be at least 5 ft (1.5 m) from the bottom before the pump is activated. Both suggestions would minimize entrainment of fry in the upper water column. Restrictions would also be recommended when dredging in known spawning grounds, to avoid entrainment of eggs. Partial restrictions may be appropriate in bodies of water of larger dimensions (>300 m wide) in which spawning grounds are present.

Table 9
Entrainment Rates (Organisms/Cubic Yard Dredged) of Fishes Reported for Dredges in Grays Harbor, Washington, and the Columbia River, Oregon and Washington

Species	Pipeline*	Hopper*	Hopper**
Staghorn sculpin *Leptocottus armatus*	0.001	0.016-0.092	>0.01
Pacific sanddab *Citharicthys sordidus*		0.003-0.076	
Pacific tomcod *Microgadus proximus*		0.008	>0.001
Snake prickleback *Lumpenus sagitta*		0.008-0.135	
Prickly sculpin *Cottus asper*	0.004	0.020	
Saddleback gunnel *Pholis ornata*	0.023	0.005	
Three-spined stickleback *Gasterosteus aculeatus*	0.004		
English sole *Parophrys vetulus*	0.001	0.035	
Northern anchovy *Engraulis mordax*		0.018	
Sand sole *Psettichthys melanostictus*		0.003	
Speckled sanddab *Citharichthys stigmaeus*		0.003	
Lingcod *Ophiodon elongatus*		0.002	
Pacific sandfish *Trichodon trichodon*		0.002	>0.001
Chum salmon *Oncorhynchus keta*	0.008		
Sand lance *Ammodytes hexapterus*			0.38
Showy snailfish *Liparis pulchellus*			>0.01
Eulachon *Thaleichthys pacificus*			>0.01
Cabezon *Scorpaenichthys marmoratus*			>0.01
Spiny dogfish *Squalus acanthias*			>0.001
Big skate *Raja binoculata*			>0.001
Poacher (Agonidae)			0.01
Perch (Embiotocidae)			>0.001
Gunnel (Pholididae)			>0.001
Juvenile flatfish			0.01
Herring and anchovy			0.01

Sources:
* Armstrong, Stevens, and Hoeman (1982).
** Larson and Moehl (1990).

Effects of Environmental Alterations on Shellfishes

Shellfish - general comments

114. The term shellfish, as used here, denotes a catch-all group of largely commercially important invertebrates including mobile crustaceans (e.g., shrimps and crabs) and sessile molluscs (e.g., oysters and clams). Marine and estuarine invertebrates display a tremendous diversity of reproductive strategies; nevertheless, analogies can be drawn between potential impacts on invertebrates and those described for fish eggs and larvae in the previous section. The fundamental demersal/pelagic dichotomy among most coastal fish egg and larval stages is somewhat more elaborate among invertebrates. For example, all commercially important crustaceans (e.g., shrimps, crabs, lobsters) maintain their developing eggs attached to abdominal appendages until hatching, lessening the risk of acute impacts due to dredging operations. However, eggs retained prior to hatching by some forms of sessile invertebrates are subject to the same potential impacts as demersal eggs of fishes. Local hydrodynamic conditions and, in some cases, active movement may contribute to the dispersal and distribution patterns of pelagic invertebrate larvae.

115. Additional concern is warranted with regard to sessile forms of estuarine and coastal invertebrates (e.g., oysters and clams). Sessile forms, having very limited powers of locomotion, can be assumed to be susceptible to long-term exposures of elevated suspended concentrations in the immediate vicinity of dredging and disposal operations. Most shellfishes, adapted to naturally turbid estuarine conditions, have adequate mechanisms (e.g., valve closure or reduced pumping activity of oysters) to compensate for short-term exposures. Dredging jobs of long duration (months), however, may exceed these defensive mechanisms.

Shellfish - suspended sediments

116. ***Discussion.*** The literature relevant to this issue has been reviewed by Stern and Stickle (1978) and Priest (1981). Because of their economic importance, crustaceans and bivalve molluscs have received the most attention. Table 10 summarizes the results of these studies.

117. Shellfish species, particularly benthic forms inhabiting turbid estuaries, are undoubtedly very tolerant of naturally elevated suspended sediment concentrations (e.g., concentrations generated during storm events and seasonal flooding conditions or even local wind and tide events) for reasonable durations. Most of the detrimental effects noted in Table 10 were responses to suspended sediment levels several to many times higher than those occurring at typical dredging operations (see Tables 3-6) and for periods of time ranging from 5 to 21 days. Reduced respiratory pumping rates observed by Loosanoff and Tommers (1948) for oysters held at suspended sediment concentrations between 100 and 4,000 mg/L are an example of a compensatory mechanism that enables these sessile bivalves to effectively limit their exposure over at least short-term durations. Davis and Hidu (1969) reported substantial (22 percent) incidences of abnormal development in American oyster eggs exposed to suspended sediment concentrations within the range expected during dredging operations, although exposure durations were not stated. In contrast, developing oyster and hard clam larvae showed enhanced growth rates at suspended sediment concentrations up to 500 mg/L (Davis 1960, Davis and Hidu 1969). Higher concentrations did hinder growth and result in increased mortality. Bricelj, Malouf, and de Quillfeldt (1984), however, reported a decreased growth rate of juvenile hard clams at concentrations above 25 mg/L.

118. Carriker (1986) provides an excellent review of the literature dealing with suspended sediment effects on oyster larvae. In general, concentrations below about 180 mg/L for embryos (in the egg membrane) and below 500 mg/L for veligers can be beneficial, while higher concentrations become increasingly harmful. Suspended sediment apparently has little effect on feeding or movement of larvae through the water column; however, toxic compounds may affect larvae of all stages, and sediment films may affect attachment of larvae to suitable

Table 10
Results of Experimental Determinations of Effects of Suspended Sediments on Various Life History Stages of Shellfishes (Modified from Priest 1981)

Species	Stage	Suspended Sediment Concentration, mg/L	Exposure Duration	Type of Sediment	Degree of Effect	Reference
American oyster	Eggs	188	Not stated	Artificial	22 percent abnormal development	Davis and Hidu (1969)
		250		Artificial	27 percent abnormal development	
		375		Natural (silt)	34 percent abnormal development	
		1,000		Artificial	No significant effect	
		2,000		Artificial	No significant effect	
	Larvae	750	12 days	Natural (silt)	31 percent mortality	
		2,000	12 days	Artificial	20 percent mortality	
		500	Not stated	Artificial	78 percent mortality	
Hard clam	Eggs	750		Natural (silt)	8 percent abnormal development	Davis (1960)
		1,000			21 percent abnormal development	
		1,500			35 percent abnormal development	
		125		Artificial	18 percent abnormal development	
		125			25 percent abnormal development	
		4,000			31 percent abnormal development	Davis and Hidu (1969)
	Larvae	1,000		Natural (silt)	No significant effect	Davis (1960)
	Larvae	500	12 days	Artificial	50 percent mortality	
Spot-tailed sand shrimp	Adult	50,000	200 hr	Artificial	LC_{50}	Peddicord et al. (1975)
Black-tailed sand shrimp	Subadult	21,500	21 days	Natural (contaminated)	20 percent mortality	Peddicord and McFarland (1978)
Dungeness crab	Adult	3,500	21 days	Natural (contaminated)	LC_{10}	
	Juvenile	2,000-20,000	25 days	Natural	No mortality at <4,300 mg/L; 38-percent mortality at 9,200 mg/L; abnormalities between 1,800 and 4,300 mg/L	Peddicord and McFarland (1978)
American lobster	Adult	50,000	Not stated	Artificial	No mortality	Saila, Polgar, Rogers (1968)
American oyster		4,000-32,000	Extended	Not stated	Detrimental	Wilson (1950)
		100-700	Not stated	Mud	No effect	Mackin (1961)
		100-4,000	Not stated	Silt	Reduced pumping	Loosanoff and Tommers (1948)
Blue mussel	Subadult	100,000	5 days	Artificial	10 percent mortality	Peddicord et al. (1975)
	Adult	100,000	11 days		10 percent mortality	
	Adult	96,000	200 hr		LC_{50}	

substrates. Peddicord and McFarland (1978) reported that juvenile American lobsters experienced no mortality after 25-day exposures to suspended sediment (contaminated) concentrations approaching 20,000 mg/L.

119. Long-term effects have received less attention than acute impacts. Nimmo et al. (1982) examined the long-term effects of suspended particulates on survival and reproduction of a mysid shrimp, *Mysidopsis bahia.* Average suspended sediment concentrations were maintained at three levels (45, 230, and 1,000 mg/L) for durations up to 28 days, sufficient time for the mysids to complete an entire life-cycle. No significant effects were observed on adults within 4 days. After 28 days, however, test mysid populations were reduced to 75 percent of controls. Nimmo et al. (1982) observed reduced numbers of juveniles produced and increased mortality of the original adult mysids with time, and speculated that suspended sediments interfered with feeding and mating behavior, clogged gill surfaces, and led to disorientation in water currents. The authors concluded that continuous long-term production of suspended particulates in excess of 1,000 mg/L could reduce populations of either planktonic or nektonic organisms in estuaries.

120. ***Summary.*** Shellfish species inhabiting turbid estuaries and coastal waters can be expected to be adapted to and highly tolerant of naturally elevated suspended sediment concentrations for reasonable durations of time. Long-term operations (months), however, may present problems in spawning and/or nursery habitats. Otherwise, there is little reason to suspect that shellfishes cannot tolerate the suspended sediment levels typical of most dredging or disposal operations.

Shellfish - sedimentation

121. ***Discussion.*** Although various coastal invertebrates exemplify a wide range of reproductive strategies, a large number of representative species produce planktonic egg and larval stages. Relatively few commercially important shellfish species (e.g., certain gastropods such as welks that employ egg cases) deposit eggs on or attach eggs to bottom sediments or hard substrates. Therefore, a concern for potential smothering effects resulting from increased sedimentation rates is less prevalent for shellfish eggs in contrast with demersal fish eggs. Certain egg and larval stages, in particular those of neutral or negative buoyancy which are subject to passive dispersal by water currents, may settle to the bottom and be smothered in project areas characterized by slack- or slow-water flows. Hence, sedimentation effects could become a factor for some species under certain site-specific circumstances.

122. Juveniles of shellfishes that assume sessile (e.g., oyster spat) or burrowing (e.g., surf clam) modes of existence may be particularly vulnerable to increased sedimentation rates in the vicinity of dredging operations. Rose (1973) and Saila, Pratt, and Polgar (1972) reported significant mortality of oysters and mussels around dredging and disposal operations, respectively, when deposited material remained in place for some time. Wilson (1950) and Ingle (1952), however, reported little apparent detrimental impact on oysters around dredging operations in situations where settled material was dissipated by currents. Ability to maintain depth position within the sediments and to remove accumulated sediments from burrows varies among species. Sedimentation rates induced by dredging operations, however, are generally no higher than those resulting from storm events and may be subsequently removed by currents. Sedimentation rates induced by disposal operations, on the other hand, may be such that burial is a concern.

123. Relative organism size will influence whether burial will occur. Although meiofaunal organisms such as nematodes and harpacticoid copepods are relatively mobile, they may be more affected by sedimentation than larger less mobile macrofauna simply based on scale.

124. In addition to smothering effects, increased sedimentation could manifest itself in other ways. Frequent repositioning to maintain a relative distance to the sediment-water interface requires that a shellfish shift its energetic allotments away from other functions such as growth or reproduction. Trueman and Foster-Smith (1976) have suggested that the energetic costs of

burrowing can be quite large. In a similar vein, shellfishes such as infaunal shrimps that maintain extensive burrow systems, often with multiple surface openings, will need to increase maintenance operations to prevent infilling.

125. The ability of certain benthic organisms to burrow through varying amounts of overburden has been well documented (Glude 1954, Maurer 1967, Shulenberger 1970, Westley et al. 1973, Diaz and Boesch 1977, Chang and Levings 1978, Stanley and DeWitt 1983, Maurer et al. 1986). In most of these cases the organisms studied were capable of moving up through as much as 10 to 30 cm of material without significant mortality. Factors such as particle size and the rate of sediment deposition must, however, be considered. The long-term effects of rapid sedimentation episodes are not well understood. As noted by Diaz and Boesch (1977), low-density fluid muds produced from fine-grained material can present severe problems for benthic organisms. This type of material is highly unstable, provides little physical support, and has a low oxygen concentration, which hinders respiration and feeding.

126. An additional concern involves the possible hindrance of settling by oyster larvae on hard surfaces covered by silt. Galtsoff (1964) suggested that as little as 1 to 2 mm of silt may be sufficient to prevent settling on shell cultch. As pointed out by Carriker (1986), however, the fact that larvae can attach to surfaces fouled by mucoid films, microbes, and detritus suggests that oyster larvae are indeed capable of dealing with relatively unclean surfaces.

127. ***Summary.*** Sessile or sedentary species will be most vulnerable to adverse impacts, the most obvious of which are burial and smothering of organisms. This is especially important in waters characterized by slack-water or low-flow conditions where high sedimentation rates will occur following suspension of sediments by dredging/disposal activities. Organisms that are sessile will simply be buried in situ at high sedimentation rates, but mobile and active burrowing organisms may also be affected when sedimentation rates are sufficiently high to result in burial, as may occur during disposal operations. Concern may also be warranted when low-density fluid muds are involved.

Shellfish - entrainment

128. ***Discussion.*** Both demersal and pelagic eggs, larvae, and juveniles of shellfishes are susceptible to entrainment by suction dredges due to their inability to escape the suction field around the intake pipe. Demersal forms may be picked up directly with the sediment, while pelagic forms may be drawn in from the surrounding water column. With regard to the dungeness crabs (*Cancer magister*), which should be considered mobile, Tegelberg and Arthur (1977) reported no apparent avoidance of a dredge by crabs resting, partially buried, in the bottom sediments. Direct study of entrainment of shellfishes is limited to the dungeness crab (Tegelberg and Arthur 1977; Stevens 1981; Armstrong, Stevens, and Hoeman 1982) and the sand shrimp, *Crangon* spp. (Armstrong, Stevens, and Hoeman 1982), both of which were studied in Grays Harbor, Washington. The only other consideration of entrainment involved a workshop on the potential for entrainment of larval oysters (American Malacological Union 1986), discussed at the end of this section.

129. Entrainment rates for dungeness crabs and sand shrimp by clamshell, hopper, and pipeline dredges are summarized in Table 11. Rates of entrainment of dungeness crab ranged from 0.035 to 0.502 crab/cubic yard and were lowest for clamshell dredges followed by pipeline and hopper dredges. Overall mortality of those organisms entrained was highest for pipeline dredges (100 percent) versus hopper dredges (56 to 73 percent) (Stevens 1981; Armstrong, Stevens, and Hoeman 1982), given differences in delayed mortality. In the case of clamshell dredges, mortality is restricted to potential burial and abrasion during transport or deposition of dredged material, while suction dredges may impart additional damage from the suction mechanisms and, in the case of hopper dredges, the splash plates used to disperse material within the hopper. The 100-percent mortality rate reported for crabs entrained by pipeline dredges reflects the entrainment of crabs

within diked disposal areas, from which crabs that survive passage through the dredge itself cannot escape.

Table 11
Entrainment Rates Reported for Three Dredge Types in Grays Harbor, Washington

Dredge Type	Rate*	Reference
	Cancer magister	
Clamshell	0.012	Stevens (1981)
Hopper	0.131-0.327	Tegelberg and Arthur (1977)
	0.182-0.231	Stevens (1981)
	0.055-0.518	Armstrong, Stevens, and Hoeman (1982)
Pipeline	0.0017-0.241	Stevens (1981)
	0.015-0.200	Armstrong, Stevens, and Hoeman (1982)
	Crangon spp.	
Hopper	0.063-3.375	Armstrong, Stevens, and Hoeman (1982)
Pipeline	0.001-3.404	Armstrong, Stevens, and Hoeman (1982)

* Number of organisms per cubic yard dredged.

130. Both Stevens (1981) and Armstrong, Stevens, and Hoeman (1982) observed lower overall mortality (45.9 percent versus 85.6 percent) for small crabs (<50-mm carapace width) compared to large crabs (50-mm carapace width). Small crabs are apparently less susceptible to physical damage due to their size. Stevens (1981) estimated a potential overall mortality rate of 0.1 crab/ cubic yard for a typical dredging year in Grays Harbor, or about 100,000 crabs per year. Armstrong, Stevens, and Hoeman (1982) estimated a year-round figure for Grays Harbor of 2.6 to 3.5 million crabs and a restricted winter-only dredging figure of 2 million crabs (a reduction of 44 percent). In both cases entrainment was correlated with crab abundance. Both studies also suggested that restrictions be imposed on dredging during the summer months (March-August), when crabs were most numerous. Entrainment rates of sand shrimp were up to six times greater than the highest rates reported for dungeness crab (Table 11); however, these rates were observed during the summer months (May-August) when shrimp were most abundant. Ghost shrimp, *Callianassa californiensis*, were also reported to be entrained at a rate of 0.727 shrimp/cubic yard, but for only one area of Grays Harbor. While these rates seem insignificant taken alone, they become more meaningful when used to predict the total impact on a given population in a particular area, as was done for dungeness crab in Grays Harbor.

131. In addition to direct entrainment, Armstrong, Stevens, and Hoeman (1982) also speculated on the indirect impacts of dredging on crabs as well as other organisms. These impacts include direct removal of food sources for crabs, shrimps, and fishes; alteration of intraspecific competition; burial of crabs; and toxicant release from suspended sediments.

132. The potential for entrainment of larval oysters by hydraulic cutterhead dredges was addressed by a workshop sponsored and conducted by the US Army Engineer District, Baltimore, and the US Army Engineer Waterways Experiment Station (WES) (American Malacological Union 1986). Participants in this workshop reported on state-of-the-art knowledge about oyster distribution and biology and the physicochemical effects of hydraulic dredging operations that could potentially affect oyster larvae. The goal of the workshop was to determine if this information could be used to help predict whether entrainment of larval oysters would be problematic. From this exercise, a model of entrainment was proposed which predicted dredge-induced mortality at

rates between 0.005 and 0.3 percent of late-stage larvae (Carriker et al. 1986); thus, minimal impact would be expected. However, concern over entrainment would be justified under certain site-specific conditions, such as dredging within a narrow channel or other restrictive water body. A contrasting view of the extent of entrainment of oyster larvae was presented by Carter (1986), who predicted that larval survival (all stages) would be reduced by 12 to 51 percent through dredge-induced mortality. Both models are based on a somewhat different set of assumptions about larval biology, and both remain untested.

133. ***Summary.*** Although reported entrainment rates for shellfishes are low, the potential for entrainment of a larger percentage may be significant during certain periods of the year or under certain site-specific conditions. Both Stevens (1981) and Armstrong, Stevens, and Hoeman (1982) suggested that seasonal restrictions on dredging in Grays Harbor, Washington, would be one way to reduce mortality of dungeness crabs. This type of restriction seems justified if the resource in question is known to be highly concentrated in a given area on a seasonal basis. Additionally, the potential for entrainment is increased in restricted bodies of water, such as narrow channels, where mobile organisms may not be able to avoid the dredge or where more passive organisms may be concentrated. The importance of site-specific conditions in project areas is readily apparent and should be the foremost consideration in planning and scheduling dredging/disposal operations.

Effects of Environmental Alterations on Benthic Assemblages

Benthos - general comments

134. Benthic communities, as discussed here, comprise a general category including both hard- and soft-bottom assemblages (e.g., mollusc beds, grass beds, coral reefs, etc.). Kendall (1983) provides an excellent review of the role of physical-chemical factors in structuring subtidal marine and estuarine benthos. Effects on fish and shellfish spawning grounds have been discussed in previous sections. In addition to direct disturbance through removal, sedimentation, and chemical contamination, concerns have also been raised about recovery of the given assemblage after disturbance and the relative resource value of the resulting assemblage as compared to what previously existed. The difficulties encountered in seeking answers to these questions reflect our limited understanding of how organisms in these habitats are adapted to often highly variable environmental conditions.

135. A number of studies (Loucks 1970, Holling 1973, Orians 1974, Oliver et al. 1977, Sutherland 1981) point to a positive relationship between community resilience (rate of recovery from disturbance) and environmental and community variability (e.g., higher variability, faster rate of recovery). To a larger degree this relationship reflects the life history characteristics of the organisms inhabiting a given area and, to a lesser degree, chance. Both factors are themselves related. Consideration should also be given to the dredging/disposal-induced physical changes to the habitat (e.g., alteration of grain size, slope, compaction, etc.) and how these parameters can affect the nature of the resultant community. This is a particularly important concern relative to beach nourishment projects (Naqvi and Pullen 1982, Nelson and Pullen 1985). Timing of disturbance is also quite important since many benthic species have distinct peak periods of reproduction and recruitment. Recovery of a community disturbed after peak recruitment, therefore, will be slower than of one disturbed prior to peak recruitment. A general consensus among researchers reporting on effects of dredged material disposal (Boone, Granat, and Farrell 1978; Tatem and Johnson 1978; Wright, Mathis, and Brannon 1978) is that impacts on benthic communities are primarily physical (e.g., burial) and not chemical (e.g., bioaccumulation).

Benthos - suspended sediment/sedimentation

136. ***Discussion.*** The effect of burial of benthic organisms largely depends on the ability of organisms to migrate upward through the overlying deposits (see paragraphs 121-127). In the case of sedentary species (e.g., oysters, coral reef organisms), relatively small quantities of silt may be enough to cause high rates of mortality, especially in coral reef organisms that are highly intolerant of silt. Saila, Pratt, and Polgar (1972) and Rose (1973) reported mortality of oysters and mussels from direct burial associated with disposal and dredging operations, respectively. Wilson (1950) and Ingle (1952), however, reported no apparent impact to oysters around dredging operations in situations where settled material was dissipated by currents. In addition to quantity of material, the physical properties or quality of the material may also be an important consideration. As noted by Diaz and Boesch (1977), low-density fluid muds produced from disposal of fine-grained materials present immediate problems for benthic organisms; however, recovery did occur within a few months. This type of material is characterized by instability and low oxygen concentration, which provides little physical support for organisms, hinders respiration, and inhibits feeding. In the case of beach nourishment projects, the type of material deposited (sand, silt, clay) and its physical characteristics can have important consequences to the organisms being covered and controls the assemblage that will subsequently develop there (Naqvi and Pullen 1982, Reilly and Bellis 1983, Nelson and Pullen 1985).

137. In addition to direct smothering and/or burial, suspended sediments and/or a blanket of silt can affect organisms by hindering their settlement on hard substrates and by screening out incoming light. In the case of oyster larvae, a layer of silt only 1 to 2 mm thick can physically hinder the attachment of settling larvae (Galtsoff 1964). In addition, sediment particles may act to hinder or block attractive chemical cues on hard substrates or waterborne pheromones (Crisp 1967, Hidu 1969), thereby preventing attachment. It is likely that silt may affect a number of organisms in this way. Carriker (1986) points out, however, that the fact that oyster larvae can attach to surfaces covered by mucoid materials, microbes, and detritus suggests that oyster larvae are indeed capable of dealing with relatively unclean surfaces.

138. Light attenuation may be either detrimental or beneficial depending on the organism. In the case of submersed plants, high turbidity or a deposit of silt on leaf blades has the potential to substantially reduce photosynthetic activity, although quantitative estimates have not been determined (Zieman 1982; Thayer, Kenworthy, and Fonseca 1984). Similarly reduced light levels over coral reefs can affect growth of symbiotic algae (zooxanthellae) (Courtenay et al. 1972, Bak 1978). However, in the case of oyster larvae, reduced light levels may act to simulate the shaded conditions on the underside of shell material, the preferred settling site (Ritchie and Menzel 1969). These authors point out that the effect would be increased settling of the late-stage larvae. Another possible effect of a turbidity screen would be the protection of gametes and larvae from the detrimental effects of ultraviolet radiation near the surface (Wilber 1971). As pointed out by Carriker (1986), however, these and other effects of suspended sediment and silt, although interesting possibilities, remain unstudied.

139. ***Summary.*** A high rate of sedimentation, particularly for disposal operations, is an obvious concern because of the potential for burial of benthic communities. Sedentary organisms (reef-forming molluscs, submersed plants, coral reefs, etc.) are particularly vulnerable to burial. Less severe but potentially damaging films of silt or suspended sediment plumes may affect feeding, respiration, or photosynthetic activity.

Benthos - bottom disturbance/recolonization

140. ***Discussion.*** Whether a benthic assemblage is destroyed by a dredging operation or is buried by sediment, concerns have been raised about the significance of the loss as it relates to organisms that depend on this resource for food. Benthic organisms are important food sources for a host of demersal fishes and shellfishes of all stages (juvenile-adult). At present, however, little is known about how much production a given benthic community can support and even less is known about the relative importance of different types of assemblages (vegetated versus nonvegetated, early- versus late-successional stage, etc.) to production. Major points of contention in this debate are questions about rates of recovery of benthic assemblages after impact and the relative importance of early- versus late-successional stages of the postimpact community as forage for fishery resources.

141. Recovery rates of macrobenthic assemblages following both dredging and disposal operations generally range from only a few weeks or months to as much as a few years, depending upon the type of project (dredging, disposal), the nature of the bottom, physical characteristics of the environment, and the timing of disturbance. Most disposal operations result in initial smothering of organisms, followed by rapid recovery within weeks or months (Pfitzenmeyer 1970; Saila, Pratt, and Polgar 1972; Leathem et al. 1973; Maurer et al. 1974; Oliver et al. 1977; Bingham 1978; Boone, Granat, and Farrell 1978; Tatem and Johnson 1978; Wright, Mathis, and Brannon 1978; Bokuniewicz and Gordon 1980). Other studies have reported minimal or no impact on macrofaunal assemblages under conditions of high current flows that acted to dissipate suspended materials (Van Dolah et al. 1979; Van Dolah, Calder, and Knott 1984; LaSalle and Sims 1989). Similar short-term recovery rates, following natural defaunation events (e.g., storms anoxia), have also been reported (Saloman and Naughton 1977, Simon and Dauer 1977). Meiobenthic assemblages, on the other hand, have been reported to have very low rates (years) of recovery (Rogers and Darnell 1973, Pequegnat 1975, Rogers 1976). For reviews of impacts from beach nourishment, see Naqvi and Pullen (1982) and Nelson and Pullen (1985).

142. In the case of maintenance dredging operations, minor impacts have been reported (Stickney and Perlmutter 1975; McCauley, Parr, and Hancock 1977), while for shell dredging, initial reduction in benthic abundance was followed by rapid recovery (Harper 1973). Dredging of new channels, however, may result in drastic and long-term (years) changes in nearby macrofaunal assemblages (Taylor and Saloman 1968; Kaplan, Welker, and Kraus 1974), in part due to changes in the hydrologic regime and potential alteration in salinity patterns.

143. A number of studies (Loucks 1970, Holling 1973, Orians 1974, Oliver et al. 1977, Sutherland 1981) point to a positive relationship between community resilience (rate of recovery) and environmental variability—communities inhabiting highly variable habitats have higher rates of recovery. To a large degree this relationship is related to the life history characteristics of the organisms comprising the assemblage and the timing of the disturbance (Rhoads, McCall, and Yingst 1978; Rhoads and Boyer 1982). High reproduction and turnover rates and high dispersal ability allow opportunistic species to colonize newly exposed material very rapidly, and in fact, these abilities allow these species to inhabit highly variable environments. Timing of disturbance is also quite important since many benthic species have distinct peak periods of reproduction and recruitment.

144. The nature of the assemblage in terms of species composition will also vary depending on both the availability of species in adjacent areas and, to some degree, chance events. Pearson (1975) describes two stable benthic assemblages that develop after an oxygen depletion event (induced by organic enrichment) defaunates the bottom. Initial colonization of either assemblage is largely a chance event. Each assemblage is composed of two or three dominant species. Once such an assemblage colonizes the bottom, it is capable of blocking establishment of the second. A

general pattern of marine succession, as proposed by Rhoads, McCall, and Yingst (1978), entails a deterministic progression of colonizers governed by facilitation (each assemblage in the succession enhances the development of the next). Homziak (1985), however, describes estuarine succession as a stochastic process governed more by the availability and composition of colonists, which are to a large degree chance events. Brenchley (1981) points to the importance of certain species' ability to affect colonization by other species. She suggests that physical events, such as bioturbation of the sediment (e.g., burrowing activity), act to control community structure and may be more important than the previously implied importance of key species (e.g., keystone predators) in certain trophic levels.

145. Predicting a rate of recovery and the nature (composition) of the resultant assemblage is not always possible. In general, however, comparisons of the nature of early- versus late-stage species comprising assemblages can be made and related to their value as a food resource for other species (Rhoads, McCall, and Yingst 1978). Early colonists tend to be opportunistic species characterized by small size, rapid growth, short life span, and high rates of turnover and reproduction. These species are readily attracted to newly available sources of organic carbon, which usually characterize newly disturbed sediments. These organisms inhabit the surface layers of the bottom and are readily available to epibenthic and demersal predators. By comparison, later arriving species are characterized by larger size, slower growth, longer life span, and slower rates of turnover and reproduction. These species live at greater depths in the sediment and are, therefore, less readily available to predators (for details, see Rhoads, McCall, and Yingst 1978 and Rhoads and Boyer 1982). From this comparison it can be predicted that, from a fisheries standpoint, early-stage assemblages may be of higher value by virtue of high production and availability.

146. To evaluate the relative value of such bottom assemblages to fisheries production, the Benthic Resources Assessment Technique was developed by the Environmental Laboratory, WES (Clarke and Lunz 1985). Application of the technique by Lunz (1986) has shown that early successional assemblages, established on dredged material disposal sites, have higher fisheries value in terms of available biomass and higher potential usage by benthic feeding fishes (particularly juveniles) than nearby reference areas. In effect, disturbance by dredged material disposal (burial of the preexisting assemblage) serves to reset the progression of the assemblage along a successional gradient, as would naturally occur following storm events. These observations should not be misinterpreted as suggesting that early-successional assemblages are "better" and/or of higher "value" in terms of all functional parameters than late-stage assemblages. For example, late-successional stages do serve other equally important functions in sediment processes, such as organic matter turnover and aeration.

147. ***Summary.*** Given the highly variable nature of most estuarine and marine benthic assemblages, disturbances by dredging/disposal activities usually represent relatively minor and short-lived impacts, similar to those induced by storm events, oxygen depletion events (natural or industrially induced), and other disturbances. Some concern, however, may be warranted in cases when the areal extent of impacted bottom represents a large proportion of the parent body of water. In that event, some consideration should be given to the characteristics of the habitat itself (e.g., highly variable versus relatively stable) and the relative condition of the unimpacted area, given its potential value to the overall ecosystem. When possible, consideration should also be given to scheduling activities before peak periods of recruitment by the benthic fauna. This would help decrease the recovery time for the assemblage.

Effects of Environmental Alterations on Endangered Species, Sea Turtles, Marine Mammals, and Colonial-Nesting Birds

Endangered species - general comments

148. Issues involving endangered species are based largely on concerns about disturbances to critical physical habitat and/or noise interruptions of nesting/breeding activities. In the case of the latter, seasonal restrictions applied to dredging/disposal operations are common (Table 1), and in many cases, criteria concerning a buffer zone around a site are designated. Operations are permitted outside this zone. Similarly, issues involving sea turtles, marine mammals, and colonial-nesting birds largely concern disturbance of nesting areas, either directly through physical alteration or indirectly through noise disturbance in proximity to a nesting/breeding site. A particular concern about turtle nesting areas is the potential effect of beach nourishment operations on nesting. In the case of colonial-nesting bird sites, particularly those on dredged material disposal sites, concerns include either periodic placement of new dredged material on the island or noise disturbance by dredging/disposal operations in the immediate vicinity of a colony. Issues involving direct effects will be discussed under the heading of habitat disturbance, while indirect effects will be discussed under the heading of noise disturbance. In addition to these habitat-related issues, the issue of interference with movement (e.g., channel blockage) of marine mammals in restricted areas and the potential entrainment of sea turtles in channel areas have also been raised.

Endangered species - habitat disturbance

149. ***Discussion.*** Habitat disturbance, as discussed here, involves any direct physical alterations to sites used by the resource in question. Direct disturbance of "critical habitat" of an endangered species is generally not permissible and, therefore, is not a concern relative to seasonal restrictions. However, in the case of sea turtles (many of which are endangered or threatened), loss or alteration of suitable beach nesting sites may represent a significant negative impact to a population. In the case of colonial-nesting birds, particularly those using dredged material islands, activities associated with periodic deposition of additional dredged material may also represent a significant negative impact.

150. Impacts to sea turtle nesting sites include burial of existing nests, alteration of substrate composition, and compaction of sediments (Nelson and Pullen 1985). Burial of nests can be avoided through timing of activities; however, changes in substrate characteristics and composition can be critical. The ability of an adult turtle to excavate a nest or a newly hatched nestling to dig out of a nest is directly affected by substrate type and composition. With this in mind, care should be exercised in choosing borrowed material for beach nourishment, as well as in avoiding compaction of the newly placed material by equipment. Nelson and Pullen (1985) discuss a number of additional potential problems and precautions aimed at minimizing impacts during beach nourishment.

151. A large number of colonial-nesting birds use dredged material islands as nesting sites, which are periodically renourished by addition of newly dredged material. A considerable amount of research effort has gone into design, development, and management plans for such islands to maintain them as suitable nesting sites for a wide variety of birds. Landin (1986) provides a good overview of the history of development and usage of these islands as bird habitat, and outlines considerations to be followed during habitat manipulation.

152. ***Summary.*** Impacts to turtle nesting sites from beach nourishment operations may have considerable consequences to nest-building adults and/or hatchlings emerging from a nest. Similarly, placement of dredged materials onto dredged material islands may affect reproductive success of colonial-nesting birds using these islands. In both cases, operations should be restricted to non-nesting periods to minimize impacts. For turtles, this includes both adult nest-building and hatchling emergence periods.

Endangered species - noise disturbance

153. ***Discussion.*** Human activities near the nesting sites of any animal have the potential to disrupt behavior, which may lead to lowered hatching success or nest abandonment. In the case of some colonial-nesting birds, noise disturbances may lead to adult birds leaving the nest, which may affect the eggs or young chicks in a number of ways. Nervous adult birds may accidentally crush or knock eggs or young out of nests. Prolonged absence of an incubating adult bird may effectively increase incubation time and may increase exposure of both eggs or young chicks to the environment and predators. Additionally, activities in the vicinity of colonies or feeding grounds may affect the birds' ability to gather food for themselves and their chicks.

154. ***Summary.*** It has been suggested that dredging/disposal activities on or in the vicinity of dredged material islands, as well as other colonial-nesting bird colonies, be restricted to nonbreeding seasons to avoid disturbances to the birds (Landin 1986). Activities may be allowable outside a buffer zone (about 100 m) around the nesting site.

Effects of Chemical Release on Organisms

Discussion

155. Concern is always warranted when dealing with sediments known to be contaminated with heavy metals, hydrocarbons, or other potentially toxic compounds. The possibility exists that contaminants, released by sediment suspension, may adversely affect organisms in a number of ways. Contaminants may become adsorbed onto eggs and ingested or absorbed by larval, juvenile, or adult forms (Cairns 1968). Organisms may bioaccumulate contaminants through feeding (Chen et al. 1976; Nathans and Bechtel 1977; Burks and Engler 1978; Neff, Foster, and Slowey 1978; Kay 1984; Rubinstein, Gilliam, and Gregory 1984). It appears, however, that soluble fractions of most compounds have greater effects than sediment-sorbed fractions. Evidence also suggests that many contaminants may lower the threshold concentration of suspended sediments at which detrimental effects on survival and development of eggs and larvae are produced. These effects may take the form of altered morphology, physiology, behavior, and/or pathology in fish (Sindermann et al. 1982) and shellfish (Tagatz 1976; Farr 1977, 1978). For example, the exposure of the grass shrimp *Palaemontes vulgaris* to sublethal concentrations of mirex (Tagatz 1976) and *Palaemontes pugio* to sublethal concentrations of parathion and methyl parathion (Farr 1977, 1978) impaired both species' antipredatory behavior to predatory fishes, resulting in increased mortality in controlled experiments.

156. In general, water-soluble fractions of compounds have a greater effect on organisms than sediment-sorbed fractions. In addition, toxicity is more pronounced under conditions of low salinity and high temperature. The enormous diversity of chemical compounds and possible synergistic effects further complicate the issue. Good general reviews of the literature on the availability and bioaccumulation of heavy metals, petroleum hydrocarbons, synthetic organic compounds, and radionuclides contained in sediments are provided by Kay (1984) and Olsen (1984). More specific information on the toxicity, sublethal effects, and bioaccumulation of selected chemical compounds on various organisms is given by Eisler (1985a,b,c,d; 1986a,b,c,d; 1987a,b; 1988a,b,c) and Eisler and Jacknow (1985).

Summary

157. In light of the concerns outlined above, existing regulatory guidelines for the management of contaminated sediments (USEPA/Corps of Engineers 1977) should be consulted whenever dredging activities involve such sediments. Seasonal restrictions on dredging/disposal operations in these areas may be justified during periods of high biological activity.

Effects of Dissolved Oxygen Reduction on Organisms

Discussion

158. The reduction of dissolved oxygen (to levels below 1 to 2 ppm) has the potential to affect nonmobile organisms or life history stages (e.g., demersal eggs) in the vicinity of a dredging and/or disposal operation. Morrison (1971) reported that the eggs of the hard clam, *Mercenaria mercenaria*, were tolerant of oxygen concentrations as low as 0.5 ppm, with death occurring only at 0.2 ppm. Available information (see Part IV) suggests that, in typical dredging/disposal operations, reductions in dissolved oxygen are restricted to the bottom waters (in fluid mud) and are short-term phenomena (on the order of hours). Sediments having a high organic content and those affected by organic loading (e.g., sewage sludge) may, however, cause significant reductions in dissolved oxygen (Brown and Clark 1968) for longer periods of time. As with sedimentation, mobile juvenile and adult organisms are capable of avoiding localized areas of low oxygen content.

Summary

159. The apparent relationship between suspended sediment concentration and levels of dissolved oxygen leads to recommendations similar to those presented earlier for suspended sediments. Given the levels of suspended sediment and associated short-term reductions in dissolved oxygen around typical dredging/disposal operations, impacts should be minimal. Detrimental effects on demersal eggs and larvae would not be expected, except in cases of long-term disposal operations when dissolved oxygen levels are kept low for extended periods.

Effects of Channel Blockage on Organisms

Discussion

160. Channel blockage, by the physical presence of the dredging/disposal equipment or by the suspended sediment plume, is suspected to have an effect on the distribution and movement of juvenile and adult organisms, particularly anadromous fishes, turtles, and some marine mammals. In the case of fishes and shellfishes, the only available information on the subject consists of a few observations of the attraction of fishes and shellfishes to dredging operations (Ingle 1952, Viosca 1958, Maragos et al. 1977) and a report of trawl data taken in a dredge disposal plume versus "clear" ambient water (Harper 1973).

161. In the case of fishes, the average number collected in clear water was quite similar in summer and winter; the average number of individuals in turbid plume waters was much larger in winter (Harper 1973). Only one species (bay anchovy, *Anchoa mitchelli*) showed a pronounced tendency to avoid the plume during the summer, while another (Gulf menhaden, *Brevoortia patronus*) showed a preference for clear water in summer and winter. Additional comparisons of fish abundances in naturally turbid versus clear water showed that the average number of individuals and fish biomass values were higher in the turbid water during the winter but were similar during the summer. *Brevoortia patronus*, previously shown to avoid the dredge plume, was collected only in turbid waters and at high densities, suggesting that some factor other than sediment suspension may have been a factor.

162. In the case of shellfishes, the blue crab, *Callinectes sapidus*, was collected in equal numbers in both clear and turbid waters during the summer, but was collected in much larger numbers in turbid waters during the winter (Harper 1973). Brown shrimp, *Penaeus aztecus*, and grass shrimp, *Palaemontes pugio*, showed preference for turbid water, but were common components of the samples in only one season. White shrimp, *Penaeus setiferus*, seemed to have no preference for either clear or turbid water.

163. Little information is available on vertical movements of fishes or shellfishes in response to turbidity/light availability. Dadswell, Melvin, and Williams (1983) observed a direct relationship between turbidity in the water column and density of American shad (*Alosa sapidissima*) in an offshore open-water situation. In this case the fish may have been responding to ambient light levels and not directly to turbidity.

164. In the case of sea turtles and marine mammals, concerns under this topic are based on the potential for dredging/disposal equipment to directly interfere with these organisms in narrow or confined channel areas. Sea turtles are suspected of hibernating in some deep navigational channels (Cape Canaveral, Florida) during the winter (Carr, Ogren, and Moven 1980) where they may be entrained by dredges operating in these channels. Dredges operating in borrow areas in the vicinity of beach nourishment operations may also entrain young nestlings (sea turtles) coming from nearby beaches. In the case of manatees, the potential exists for dredges, barges, or support craft to directly collide with individuals or block the movement of individuals in narrow channel areas.

Summary

165. Consideration of project area morphology should be made relative to potential inhibition of movement of juvenile and adult fishes and shellfishes. Restrictions may be justified in cases where the turbidity plume generated by an operation extends across the entire waterway or channel. Given the supposition that sea turtles hibernate in some deep channel areas (Carr, Ogren, and Moven 1980) during winter, concern about potential entrainment seems justified and should be considered. Careful planning and caution during dredging operations can also minimize any impacts to turtles or mammals in channel areas.

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